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ANNUAL REPORT

# ENVIRONMENTAL RADIOACTIVITY IN CANADA
## 1980

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## ABSTRACT

The radiological surveillance program of the Department of National Health and Welfare is conducted for the purpose of determining levels of environmental radioactivity in Canada and assessing the resulting population exposures. In this report, the results for 1980 from the analyses of air, precipitation, water vapour, drinking water, milk, biota and bone for critical radionuclides are presented. Radioactivity measurements are now given in the SI unit, the becquerel (Bq). One becquerel is equivalent to about 27 picocuries. Dose commitment estimates are given in sieverts (Sv). One sievert is equal to 100 rem. The graphical format used in previous reports has been retained with extensions of the trend-lines to enable identification of changes in the levels and assessment of their potential health significance. All the levels measured during this period are below the permissible limits recommended by the International Commission for Radiological Protection.

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## INTRODUCTION

The Environmental Radiation Hazards Section of the Radiation Protection Bureau investigates the potential health effects to the Canadian population from natural and man-made sources of environmental radioactivity. This includes the evaluation of population doses from terrestrial and cosmic radiation and potential health risks from inhaling radioactivity in air or ingesting it in drinking water and food. The data are collected by operating a nationwide network of sampling stations for air, precipitation, water vapour in air, drinking water, milk and biota and through special surveys.

In summary, the following studies were made during 1980.

- The national survey on the levels of radon-222 and its daughter products in private dwellings was extended to include five cities in the prairie provinces.
- The nationwide program to study radium-226, lead-210 and uranium in drinking water supplies continued.
- The nationwide study of nuclear weapons fallout and the potential health impact of radioactive emissions from nuclear power reactors in Canada was maintained.
- The pre-operational radioactivity study in the environs of the Point Lepreau Nuclear Generating Station, New Brunswick, continued.
- The study of external radiation exposure across Canada was maintained.
- Studies comparing the health impact of radionuclide emissions from coal and nuclear powered electrical generating facilities progressed.
- A project was undertaken to determine the toxicity of uranium in drinking water.
- Further investigations were carried out on the potential health implications of the re-entry of COSMOS-954 over northern Canada.
- Improvements were made in alpha and gamma counting techniques.

## NATURAL RADIOACTIVITY

Population exposures due to natural radioactivity are evaluated from measurements of air inside public and private buildings, radiochemical analyses of drinking water supplies, and studies of the transfer of radionuclides from soil to food to man. Radium-226, radon-222 and its daughter products, and lead-210 have been selected for study because of their high radiotoxicity. In addition, total uranium is measured because of its high chemical toxicity. In general, the levels during 1980 were well within the limits for public health recommended by the International Commission on Radiological Protection (ICRP).

### National Radon Study

In the summers of 1977 and 1978 a national survey was undertaken to determine background concentrations of radon-222 and daughters in air inside private dwellings[1]. This information is needed in establishing criteria for acceptable radon gas concentrations above which remedial action would be required. It is also needed in the design of preventive measures for future building development in areas of enhanced natural radioactivity.

In the summer of 1980, this survey was completed with the addition of 3400 dwellings in the prairie cities of Winnipeg, Brandon, Regina, Saskatoon and Edmonton. Analysis of the data revealed that 7% of these dwellings had radon daughter concentrations above the reference concentration of 0.02 working levels. This is slightly greater than the results from the 1977-78 surveys in which 3% of the dwellings had concentrations above the reference level.

### Drinking Water

The program to determine natural radioactivity levels in treated drinking water and their potential impact on human health continued. Monthly composite water samples from the 12 municipalities shown in Figure 1 were analysed for radium-226, lead-210, and uranium. The network was extended to include the Canadian north with the addition of a station at Whitehorse. Determinations of lead-210 were discontinued after May because of consistently low or non-detectable values at all stations.

The results of the analysis for the 12 stations for 1980 are presented in Figures 2 to 4. For the most part the concentrations of radium-226 and lead-210 were at or near the detection limit of 0.01 Bq/L. The highest concentration reported during the year was a radium-226 value of 0.03 Bq/L at Elliot Lake. This is low compared to the maximum acceptable concentration of 1.0 Bq/L prescribed in the Guidelines for Canadian Drinking Water Quality[2].

The uranium concentrations in Figure 4 show considerable variations with time and location. The highest concentration noted was 27 µg/L for Regina during December. The annual average for this city, as for all Canadian cities, was less than the federally prescribed maximum acceptable concentration of 20 µg/L for uranium in drinking water.

During the year an analytical method was developed for the measurement of radium-226 by liquid scintillation counting of alpha particles. It is rapid and can be used for the analyses of samples containing greater than 0.2 Bq/L.

## RADIOACTIVITY FROM FALLOUT

The twenty-second atmospheric nuclear test by the People's Republic of China was conducted on October 16. Intensive monitoring was carried out across Canada for four weeks following this event. In connection with the eruption of Mount St. Helen's, Washington State, in May, special samples were collected to evaluate the radiological health hazard. For the remainder of the year regular environmental radioactivity programs were maintained.

### Surface Air and Precipitation

Monthly regional and national averages of gross beta radioactivity in surface air particulates and in precipitation are shown in Figures 6 and 7. The sampling locations are those in Figure 5. Annual average concentrations in air particulates varied from 0.0002 $Bq/m^3$ in Goose Bay to 0.0009 $Bq/m^3$ in Windsor. Deposition of gross beta radioactivity during the year varied from 0.065 $GBq/km^2$ at Inuvik to 0.26 $GBq/km^2$ at Sault Ste. Marie. Average concentrations and deposition for the entire network were similar to those observed in 1979, and from Figure 8 it can be seen that the seasonal fluctuations were also similar.

### Milk

Composite samples of whole milk collected at the locations shown in Figure 9 were analysed monthly for cesium-137 and potassium and quarterly for strontium-90 and calcium. The highest radionuclide concentrations in the network were observed at St. John's; the lowest at Saskatoon and Montreal. Regional and national averages for 1980 are shown in Figure 10. The national levels and the cesium-137 to strontium-90 ratio of 2 to 1 are comparable to those observed in other countries[3]. Annual averages were fractionally less than those observed in 1979. The trend lines in Figure 11 show that concentrations of these nuclides in milk have been only marginally affected by the relatively small atmospheric injections from weapons tests in the last four years.

### October 16 Nuclear Weapons Test

The yield of this weapons test was equivalent to 200 kilotonnes to 1 megatonne of TNT. The leading edge of the radioactive debris reached the west coast of Canada on October 19 at an altitude of 9000 to 15 000 metres. Nationwide daily monitoring of surface air for gross beta radioactivity and weekly analyses of milk were carried out from October 17 and November 14. The locations are the same as in Figures 5 and 9. In addition, special milk samples were collected in the National Capital Region. The daily air filters and monthly precipitation samples collected in October, November and December were analyzed by high resolution gamma spectroscopy.

Fresh fallout radioactivity from the test was first observed on air filters collected at ground level on October 28, 12 days after the test. The radionuclides identified on the filters and in precipitation were zirconium-95, niobium-95, molybdenum-99, ruthenium-103, iodine-131, lanthanum-140, cerium-141, uranium-237 and neptunium-239. Gross beta radioactivity in air particulates during the period of special monitoring reached levels 3 to 10 times higher than those measured during the same period in 1979. The highest value recorded at Calgary is, however, less than 1/1000 of the maximum permissible level. Table 1 compares results obtained during the special monitoring with those observed during the same period in 1979. Daily variations in gross beta concentrations are shown by region in Figure 12 along with variations in national iodine-131 concentrations. Although radioactivity levels in surface air were decreasing by mid-November -- due to radioactive decay, dilution and removal processes -- residual fallout from the test was still noticeable in December.

According to Agriculture Canada most dairy herds in Canada were still on pasture or mixtures of harvested and fresh feed when the test occurred. However, iodine-131 was not detected in any milk samples during the 4 weeks of special monitoring following the test.

Mount St. Helen's Eruption

There was some concern that the immense quantities of volcanic ash released in the Mount St. Helen's Eruption might have caused enhanced levels over Canada in the airborne concentrations of naturally-occurring radioactive elements. Consequently air filters exposed at Regina for 6-hour periods from May 17 to 23 were analyzed for gamma-emitting radionuclides and gross beta radioactivity. The short exposure times were required due to clogging of the filters by heavy dust loads. Naturally-occurring radionuclides and residual fission products were identified on the filters. The concentrations of natural radionuclides corresponded to levels normally found in soil. Gross beta radioactivity concentrations were similar to those observed at stations not affected by the ash from the eruption.

## RADIOACTIVITY FROM NUCLEAR REACTORS

Samples of air water vapour, surface water, milk and biota are collected on a regular basis from the vicinity of 6 nuclear sites in Canada:

- The Whiteshell Nuclear Research Establishment (AECL-WNRE), Pinawa, Manitoba.
- The Bruce Nuclear Power Development (BNPD), Tiverton, Ontario, with a 220 MW(e) prototype generating station, four 750 MW(e) units in service and four 750 MW(e) units under construction.
- The Pickering Nuclear Generating Station (PNGS), Pickering, Ontario, with four 500 MW(e) units in service and four 500 MW(e) units under construction.
- The Chalk River Nuclear Laboratories (AECL-CRNL), Chalk River, Ontario.
- The Nuclear Power Demonstration Reactor (NPD), 25 MW(e), at Rolphton, Ontario.
- The Gentilly Nuclear Site (GNS), Gentilly, Quebec, with a 250 MW(e) prototype reactor, and a 600 MW(e) reactor under construction.

In addition, the pre-operational study in the environs of the 600 MW(e) Point Lepreau Nuclear Generating Station, New Brunswick, continued. Sampling locations are shown in Figures 13 to 19. Airborne radioactivity measurements continued in the vicinity of the McMaster University research reactor, Hamilton, Ontario. The potential radiological impact from visits by nuclear vessels to the east coast were studied. In general, the results for 1980 have shown that releases from the installations were not a significant health hazard according to the recommendations of the ICRP.

In 1980 concern was expressed in Nova Scotia regarding the possible impact of radioactivity from the Point Lepreau reactor when it begins operating and also from reactors currently operating in the northeastern United States. At the request of the province, three new monitoring stations - two air and one milk - were established. Data from these stations will augment the information collected through the national fallout monitoring network and the Point Lepreau monitoring program.

The air monitoring stations, located at Digby and Greenwood, collect air particulate, atmospheric water vapour and precipitation. Raw milk is collected from a pooled sample representative of the Annapolis Valley. As expected, air, precipitation and milk results were similar to those observed at other Maritime locations. Tritium concentrations were less than the minimum detectable activity of 20 Bq/L.

Air Water Vapour

Atmospheric water vapour is collected in metallic cells containing molecular sieve. They are placed around BNPD, PNGS and GNS. Air, drawn through the cells over a period of a month, deposits atmospheric moisture on the sieve. Subsequently, the cells are heated to desorb the water which is then analyzed for tritium. The results for 1980 are shown in Figures 20 to 22. The highest concentration was observed at Station 4, 1.5 km northeast of PNGS. As shown in Figure 23, the highest levels around the 3 sites were similar to those measured during the past three years. All levels were less than those considered significant to health by the ICRP.

Water

Untreated water is collected daily at drinking water intakes on the Winnipeg River, Lakes Huron and Ontario, the Ottawa River and the St. Lawrence River (Figures 13 to 18). Sampling at the Pickering drinking water intake has been discontinued as the pumping station closed in October. Results of quarterly analysis for cesium-137 and strontium-90 are given in Figures 24 to 26. Concentrations of both radionuclides remained within normal seasonal fluctuations and were not discernable above residual fallout levels. The highest concentrations measured, 0.04 Bq/L strontium-90, and 0.01 Bq/L cesium-137 were factors of 25 and 500 respectively, below the target concentrations recommended for Canadian drinking water[2].

Milk

Weekly samples of raw milk from the vicinity of BNPD and WNRE are analyzed for iodine-131, cesium-137 and potassium. Iodine-131 was not detected at either location. The cesium-137 levels in raw milk from these sites were similar to those in the pasturized milk from the national network. The results, shown with the long-term national average in Figure 11 confirm the observations that these radionuclide concentrations around the reactor locations are due mainly to residual fallout.

Biota

Biota is sampled semi-annually. Fish from several sites on the Ottawa River were received during 1979 for analysis for strontium-90, cesium-137, calcium and potassium. The purpose is to assess the health significance of these radionuclides in this particular link of the food chain, as fish are an important dietary item for Canadians.

Point Lepreau Study

This is the first Canadian reactor to have potential impact on the population through a marine environment. Online reactor operations are scheduled for 1982. Preoperational monitoring continued with measurements of tritium in atmospheric water vapour and radionuclides in drinking water.

During 1980, in cooperation with the Province of New Brunswick, five atmospheric water vapour collection units were installed in the vicinity of the reactor site. A sixth unit was placed with the air and precipitation monitoring equipment at the Fredericton airport. Collaborative measurements of tritium in atmospheric water vapour with the Health Physics Department of the New Brunswick Electric Power Commission continued. During 1980, tritium concentrations were close to or below the current detection limit of 20 Bq/L.

Concentrations of cesium-137 and strontium-90 of 0.001 and 0.004 Bq/L, respectively, in well water from Welsh Cove were similar to those observed in 1979. As noted previously[4], adsorption on clays above the aquifer may be responsible for the strontium-90 concentration which is an order of magnitude lower than typical levels in surface water. The well is 23 metres deep. Surface water from Spruce Lake contained concentrations of 0.007 Bq/L, cesium-137 and 0.02 Bq/L, strontium-90. The concentrations are similar to those observed in other regions across Canada.

McMaster University

Gross beta radioactivity levels on daily air filters were normal.

Nuclear Vessels

Eight nuclear submarines visited Shearwater, Nova Scotia, during 1980. Gross beta radioactivity was measured on air filters and gross gamma radioactivity on seawater samples collected before, during and after the visit. No activity was found that could be attributed to a release from the vessels.

## EXTERNAL RADIATION EXPOSURE

Measurements of external gamma radiation dose rates are done quarterly at 13 environmental stations and at 14 locations around 3 nuclear reactor sites using thermoluminescent dosimeters (TLDs). Enhanced dose rates in the vicinity of nuclear reactors would be indicative of radioactive releases from nuclear operations. Figure 5 shows the 13 cities in which environmental dose rate measurements are made. The TLDs are attached to the weather housing of the air sampling equipment. Figures 13 to 15 show the 14 locations used for reactor environs monitoring at BNPD, PNGS and GNS. At these sites, the TLDs are attached to the housing of the air water vapour collection units.

Quarterly results of 1980, together with the yearly cumulative values, are reported in Tables 2 and 3. Occasionally TLDs are lost in transit or through vandalism while deployed on site. No value is reported in such cases; however, in determining the cumulative value, the average value for the remaining quarters is assumed. The values in Table 2 from the environmental stations give an indication of the range of normal background dose rates across Canada. The values from the reactor environs in Table 3 fall within the same range which shows that these doses are attributable to normal background radiation.

In order to expand and upgrade the existing reactor and environmental monitoring network, the suitability of various TLD systems was investigated. A Victoreen 2810 Reader with glass-encapsulated $CaF_2$ chips was chosen as the system most suited for measuring environmental levels of radioactivity.

## INTERCOMPARISON PROGRAM

Laboratory quality control programs continued through participation in interlaboratory comparisons sponsored by the United States Environmental Protection Agency, the World Health Organization and the International Atomic Energy Agency.

## RESEARCH PROJECTS

Energy Impact Study

In 1979 a project was undertaken to compare the health impacts of radionuclide emissions from the coal-fired generating station at Nanticoke on Lake Erie, and the nuclear generating station at Pickering on Lake Ontario. This has involved the analyses of coal and ash samples from the Nanticoke station; environmental studies of air filters, precipitation, soil and vegetation at the sites shown in Figures 14 and 27; and the analyses of ash and water samples from the storage lagoon at Nanticoke and an ash disposal pit near Toronto. A more detailed description of the program, together with some preliminary results, were presented in a previous report[5].

Gamma ray analyses were aided by the acquisition of a new intrinsic germanium detector interfaced to a PDP-8 computer. The detector has a relative efficiency of 14.4% and an energy calibration which is linear down to 5 KeV. It greatly enhances both the identification of radionuclides and the measurement of low energy gamma and X-rays.

Results are now available for over one year of regular sampling. Gamma spectrometric analyses of feed coal and fly ash at Nanticoke are summarized in Table 4. The coal values represent annual averages of weekly composite samples, whereas the fly ash and bottom ash results are from single samples taken in August. The uranium and thorium concentrations were calculated by assuming secular equilibrium between uranium-238 and radium-226 and between thorium-232 and radium-228. It can be seen that the radionuclide concentrations in ash are enriched by factors of 7 to 8 with respect to coal. There appears to be little difference between fly ash and bottom ash, except for a slight potassium-40 excess in bottom ash.

The results of the gamma spectrometric analyses of air filters are summarized in Table 5 for the fourth quarter of 1979 and for all of 1980. Values from the various sampling locations near each station have been averaged. It can be seen that over 98% of the activity arises from beryllium-7 and lead-210, with the remainder coming from potassium-40 and long-lived fission products. Potassium-40 is measurable only in the summer and early fall, when dry conditions are conducive to the suspension of soil particles. The high value of cerium-144 in the fourth quarter of 1980 at Nanticoke is presumably the result of the Chinese weapons test on October 16.

An enhancement at Pickering of the fission products ruthenium-106, antimony-125, cesium-137, or cerium-144 would indicate a possible contribution from the nuclear reactors. An enhancement at Nanticoke of naturally-occurring radionuclides such as potassium-40 or lead-210 would indicate a possible contribution from coal combustion. No such trends are apparent, apart from a slight excess of lead-210 at Nanticoke. Details of the distributions of cesium-137 around Pickering and of lead-210 around Nanticoke are given in Tables 6 and 7

respectively. The concentrations are not significantly enhanced at the downwind sites (nos. 4, 5, 8 at Pickering; nos. 3, 4, 5 at Nanticoke).

Radiochemical analyses of water samples from the ash storage lagoon at Nanticoke and the disposal pit at Toronto showed that radium-226 and lead-210 concentrations were generally below the detection limit of 0.01 Bq/L. Hence, leaching of these radionuclides from ash was negligible. Dissolved radon-222 in the water was only about 0.1 Bq/L, which would preclude a large scale emanation of radon from the ash. Lagoon water samples did show dissolved uranium at concentrations of 1 to 2 µg/L. This is somewhat higher than the average for municipal water supplies (see Figure 4), but is within the maximum acceptable concentration of 20 µg/L of the Canadian Drinking Water Guidelines[2].

Analyses were carried out on sifted ash fractions from the disposal pit to determine if there was any dependence of radionuclide concentration on particle size. The results of one such analysis, shown in Table 8, do indicate a trend of increasing concentrations of radium-226 and radium-228 on finer particles. It is the finest particles (<38 micron diameter) that are most likely to be resuspended by water and wind, and, if inhaled, to be deposited in the lungs.

Future work will concentrate on more detailed radiochemical studies of the filters and precipitation for radionuclides released in coal combustion. Dosimetric models will be used to assess doses and health effects to surrounding populations for both generating stations.

Uranium Toxicity Study

The prescribed limits for the intake of uranium are at present determined by its chemical rather than its radiological properties. The Canadian guidelines[2] for the maximum acceptable concentration of uranium in drinking water (20 µg/L) are based primarily on early work with animals[6]. There is a need to redetermine the threshold for toxic effects with the standardized laboratory techniques that are available today. This is of particular importance, since the uranium concentrations in the water supplies of some Canadian municipalities are a significant fraction of the maximum acceptable concentration. It has also been suggested, particularly in the United States, that radiological properties should have the predominant influence in setting uranium standards. For these reasons, we are participating in a project with the Toxicology Research Section of the Bureau of Chemical Hazards, Environmental Health Directorate. The Toxicology Section administers uranium in the form of the uranyl ion to laboratory rats in their drinking water at concentrations varying from 0.96 mg/L to 600 mg/L. After one to three months the rats are sacrificed and subjected to a variety of pathological and chemical studies. The Environmental Radiation Hazards Section measures the uranium residues in various tissues. The procedure involves the dissolution of the rat tissues, the removal of any interfering contaminants by anion exchange, and the subsequent measurement of parts per million levels of uranium by ultraviolet

fluorescence. Results have been obtained from a 28-day preliminary study involving 60 animals. Only kidney and bone tissue from rats in the highest exposure group showed any significant residue of uranium. These results are being used to plan a more detailed 90-day uptake study.

Cosmos-954 Re-entry

Further studies were carried out in connection with the re-entry of the Soviet Satellite, Cosmos-954, over northern Canada on January 24, 1978. Drinking water samples from various Northwest Territories communities were analyzed during the summer months of 1980 in order to detect any contamination from spring run-off. No activity was observed that could be contributed to Cosmos debris. A publication describing the role of Health and Welfare in the health assessment of unrecovered Cosmos debris is under preparation.

## SUMMARY

The studies carried out during 1980 allow estimates to be made of the individual effective dose equivalent commitments (doses) for some critical radionuclides in ingestion and inhalation pathways affecting many Canadians. These are summarized in Table 9 along with annual exposures to external gamma radiation and estimates of associated risks.

The table gives the range of doses measured in each program based on the highest and lowest annual average radionuclide concentrations measured. The corresponding locations are also given. Doses from tritium in atmospheric water vapour were calculated assuming continuous annual exposure at the highest monthly concentration measured in the vicinity of the nuclear power reactor sites. Inhalation and skin absorption were considered. Canadian food consumption data[7] were used to calculate the intake of milk. Recently published ICRP dosimetric models and risk estimates were used for the calculations of doses and risks[8,9].

As noted previously[5], natural background radiation is far more significant than contributions from residual fallout from nuclear weapons tests or from nuclear reactor emissions. The doses from external gamma radiation and natural radioactivity in drinking water represent approximately 50 per cent of the total background to which Canadians are exposed. The remainder is due to cosmogenic and primordial radionuclides -- mainly carbon-14, potassium-40, lead-210 and radon-222.

The risks given in Table 9 were estimated to the nearest power of 10 because of the uncertainties in associating detriment with dose. They represent the probability of contracting fatal cancer over a lifetime. In Canada the total risk over a lifetime is approximately 0.2[10]. The risks in Table 9 are negligible in comparison.

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7. Prantl, F.A., B.L. Tracy and J.M. Quinn, "Health Significance of the Radioactive Contamination of Soils and Plants in Port Hope, Ontario". Presented at the First Annual Meeting of the Canadian Radiation Protection Association, Montreal, May 8-9, 1980.

8. McGregor, R.G., "Radon in the Home Environment", presented at the 71st Annual Conference of the Canadian Public Health Association, Ottawa, June 23-26, 1980.

9. Gerdingh, R. and B.L. Tracy, "CSNI International Benchmark Problem on Reactor Accident Consequence Models", presented at OECD Workshop, Paris, October 1980.

TABLE 1

Gross Beta Radioactivity in Surface Air
Following the Atmospheric Nuclear Weapons test
October 16, 1980
($Bq/m^3$)

| Location | Maximum Level Observed between October 17 and November 14, 1980 | Maximum Level Observed between October and November 1979 |
|---|---|---|
| Calgary | 0.0069 | 0.0004 |
| Churchill | 0.0011 | NS |
| Coral Harbour | 0.0010 | 0.0002 |
| Edmonton | 0.0031 | 0.0007 |
| Fredericton | 0.0028 | 0.0009 |
| Goose Bay | 0.0002 | 0.0002 |
| Halifax | 0.0031 | 0.0009 |
| Hay River | 0.0014 | 0.0014 |
| Inuvik | 0.0017 | 0.0008 |
| Montreal | 0.0020 | 0.0006 |
| Moosonee | 0.0012 | 0.0006 |
| Ottawa | 0.0014 | 0.0005 |
| Quebec | 0.0015 | 0.0006 |
| Regina | 0.0027 | 0.0012 |
| Resolute | 0.0011 | 0.0008 |
| St. John's | 0.0013 | 0.0005 |
| Saskatoon | 0.0042 | 0.0014 |
| Sault Ste. Marie | 0.0044 | 0.0010 |
| Thunder Bay | 0.0016 | 0.0010 |
| Toronto | 0.0025 | 0.0009 |
| Vancouver | 0.0060 | 0.0003 |
| Whitehorse | 0.0026 | 0.0010 |
| Windsor | 0.0042 | 0.0017 |
| Winnipeg | 0.0038 | 0.0015 |
| Yellowknife | 0.0013 | 0.0012 |

NS - No Sample

TABLE 2

External Radiation Dose Measurements
At Environmental Stations

| Station | Dose Rate (μGy/h) | | | | Cumulative Dose (mGy) |
|---|---|---|---|---|---|
| | Jan. Mar. | Apr. June | July Sept. | Oct. Dec. | Jan. - Dec. |
| Calgary, Alta. | 0.08 | 0.09 | 0.06 | 0.04 | 0.59 |
| Churchill, Man. | 0.08 | 0.03 | 0.05 | 0.04 | 0.44 |
| Fredericton, N.B. | 0.11 | 0.12 | 0.09 | 0.07 | 0.88 |
| Halifax, N.S. | 0.13 | 0.12 | 0.08 | 0.09 | 0.92 |
| Inuvik, N.W.T. | 0.10 | 0.07 | 0.06 | 0.04 | 0.59 |
| Ottawa, Ont. | 0.03 | * | * | * | 0.26 |
| Saskatoon, Sask. | † | 0.11 | 0.09 | 0.09 | 0.85 |
| St. John's, Nfld. | 0.17 | 0.19 | 0.10 | 0.07 | 1.16 |
| Toronto, Ont. | 0.07 | 0.07 | 0.06 | 0.05 | 0.55 |
| Thunder Bay, Ont. | 0.11 | 0.11 | * | 0.06 | 0.82 |
| Vancouver, B.C. | 0.06 | 0.09 | * | 0.04 | 0.55 |
| Windsor, Ont. | 0.06 | 0.10 | * | 0.05 | 0.61 |
| Yellowknife, N.W.T. | 0.14 | * | * | 0.04 | 0.79 |

† - Lost in Transit

* - No Sample

TABLE 3

External Radiation Dose Measurements

in the Vicinity of Nuclear Reactors

| Station | Dose Rate (μGy/h) | | | | | | | | | | | | Cumulative Dose (mGy) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BNPD | | | | PNGS | | | | GNS | | | | Jan. - Dec. | | |
| | Jan. Mar. | Apr. June | July Sept. | Oct. Dec. | Jan. Mar. | Apr. June | July Sept. | Oct. Dec. | Jan. Mar. | Apr. June | July Sept. | Oct. Dec. | BNPD | PNGS | GNS |
| 1. | 0.11 | 0.05 | 0.08 | 0.04 | -- | -- | -- | -- | 0.12 | 0.05 | 0.07 | 0.04 | 0.61 | -- | 0.61 |
| 2. | 0.12 | 0.07 | 0.08 | 0.05 | 0.12 | 0.05 | 0.05 | 0.05 | -- | -- | -- | -- | 0.70 | 0.59 | -- |
| 3. | 0.10 | 0.11 | 0.07 | 0.06 | 0.10 | 0.06 | 0.06 | 0.05 | -- | -- | -- | -- | 0.75 | 0.59 | -- |
| 4. | 0.12 | 0.08 | 0.07 | 0.06 | 0.11 | 0.10 | 0.10 | 0.10 | 0.12 | 0.06 | 0.06 | 0.04 | 0.72 | 0.90 | 0.61 |
| 5. | 0.04 | 0.06 | 0.05 | 0.04 | 0.11 | 0.11 | 0.08 | 0.05 | -- | -- | -- | -- | 0.42 | 0.77 | -- |
| 6. | 0.16 | 0.11 | 0.11 | 0.09 | 0.09 | 0.09 | 0.09 | 0.05 | -- | -- | -- | -- | 1.03 | 0.70 | -- |
| 7. | -- | -- | -- | -- | 0.07* | 0.07 | 0.06 | 0.05 | -- | -- | -- | -- | -- | 0.55 | -- |

-- Sites Not Applicable

* Toronto station, also reported in Table 7

TABLE 4

Radionuclides in Nanticoke Feed Coal and Ash

| Nuclide | Content (Bq/kg or ppm) | | | Enrichment Factor over Coal | |
|---|---|---|---|---|---|
| | Coal | Fly Ash | Bottom Ash | Fly Ash | Bottom Ash |
| $^{40}K$ (Bq/kg) | 26.4 ± 0.6 | 204 ± 4 | 245 ± 4 | 7.7 ± 0.2 | 9.3 ± 0.3 |
| $^{226}Ra$ (Bq/kg) | 12.4 ± 0.3 | 92 ± 3 | 91 ± 3 | 7.4 ± 0.3 | 7.4 ± 0.3 |
| $^{228}Ra$ (Bq/kg) | 7.5 ± 0.2 | 58 ± 2 | 61 ± 2 | 7.7 ± 0.3 | 8.1 ± 0.3 |
| U (ppm) | 1.01 ± 0.02 | 7.5 ± 0.2 | 7.4 ± 0.2 | 7.4 ± 0.3 | 7.4 ± 0.3 |
| Th (ppm) | 1.85 ± 0.04 | 14.1 ± 0.5 | 15.0 ± 0.5 | 7.7 ± 0.3 | 8.1 ± 0.3 |

TABLE 5

Summary of Radionuclide Concentrations*

in Air at Nanticoke and Pickering

($\mu Bq/m^3$)

| Radio-nuclide | Location | 1979 Oct. to Dec. | 1980 | | | |
|---|---|---|---|---|---|---|
| | | | Jan. to Mar. | Apr. to June | July to Sept. | Oct. to Dec. |
| $^{7}Be$ | Nanticoke | 2814 | 3980 | 4270 | 3490 | 3460 |
| | Pickering | 2030 | 3300 | 3380 | 3110 | 3050 |
| $^{40}K$ | Nanticoke | ND | ND | ND | 63.8 | 35.0 |
| | Pickering | ND | ND | ND | 27.0 | 39.3 |
| $^{106}Ru$ | Nanticoke | 3.0 | 3.5 | 13.7 | 3.4 | ND |
| | Pickering | 8.6 | 7.5 | 15.1 | 6.7 | ND |
| $^{125}Sb$ | Nanticoke | 4.4 | 2.5 | 8.1 | 2.4 | ND |
| | Pickering | ND | ND | 6.6 | 1.2 | ND |
| $^{137}Cs$ | Nanticoke | 6.3 | 8.7 | 23.4 | 17.4 | 6.1 |
| | Pickering | 5.4 | 7.7 | 15.6 | 12.7 | 5.1 |
| $^{144}Ce$ | Nanticoke | 9.7 | 12.4 | 27.5 | 16.8 | 56.6 |
| | Pickering | 4.4 | 7.1 | 16.6 | 10.7 | 9.1 |
| $^{210}Pb$ | Nanticoke | 931 | 775 | 378 | 806 | 502 |
| | Pickering | 466 | 456 | 303 | 709 | 620 |

* Precision is ± 30% for $^{106}Ru$, $^{125}Sb$ and $^{144}Ce$ and ± 10% for the others (68% confidence limits).

ND Non Detectable

TABLE 6

Station-by-Station Concentrations*
of Cesium-137 in the Pickering Vicinity
($\mu Bq/m^3$)

| Site No. (Figure 14) | 1979 Oct. to Dec. | 1980 | | | | Station Average |
|---|---|---|---|---|---|---|
| | | Jan. to Mar. | Apr. to June | July to Sept. | Oct. to Dec. | |
| 1 | 3.5 | 9.3 | 15.2 | NS | NS | 9.3 |
| 3 | 4.6 | 5.2 | 15.6 | 17.3 | 4.8 | 9.5 |
| 4 | 5.1 | 4.8 | 17.8 | 13.8 | 4.9 | 9.3 |
| 5 | 8.4 | 11.5 | 15.5 | 13.8 | NS | 12.3 |
| 8 | NS | NS | 14.1 | 5.9 | 5.5 | 8.5 |
| Seasonal Avg. | 5.4 | 7.7 | 15.6 | 12.7 | 5.1 | |

TABLE 7

Station-by-Station Concentrations*
of Lead-210 in the Nanticoke Vicinity
($\mu Bq/m^3$)

| Site No. (Figure 27) | 1979 Oct. to Dec. | 1980 | | | | Station Average |
|---|---|---|---|---|---|---|
| | | Jan. to Mar. | Apr. to June | July to Sept. | Oct. to Dec. | |
| 1 | 1120 | 799 | 369 | 2010 | 587 | 977 |
| 2 | 975 | 980 | 432 | 473 | 687 | 709 |
| 3 | 819 | NS | 366 | 563 | 600 | 587 |
| 4 | 673 | 545 | 326 | 377 | 510 | 486 |
| 5 | 1070 | NS | 397 | 603 | 127 | 549 |
| Seasonal Avg. | 931 | 775 | 378 | 805 | 503 | |

NS No Sample

* Precision is approximately ± 10% (68% confidence limits).

TABLE 8

Radionuclide Content in Sifted Fractions of Ash Sample

(Bq/kg)

| Mesh Size | $^{40}K$ | $^{226}Ra$ | $^{228}Ra$ |
|---|---|---|---|
| < 20 | 433 ± 20 | 117 ± 6 | 85 ± 5 |
| 20-32 | 440 ± 20 | 126 ± 2 | 99 ± 4 |
| 32-48 | 441 ± 22 | 124 ± 8 | 93 ± 3 |
| 28-100 | 437 ± 21 | 123 ± 3 | 85 ± 8 |
| 100-200 | 617 ± 13 | 142 ± 5 | - |
| 200-400 | 507 ± 29 | 155 ± 4 | 101 ± 4 |
| > 400 | 544 ± 28 | 170 ± 4 | 106 ± 10 |

TABLE 9

Summary of Doses and Implied Risks

Determined through the Environmental Radioactivity

Monitoring Program during 1980

| Exposure Mode | Dose Range (mSv) | Location | Implied Risk |
|---|---|---|---|
| External Gamma Radiation | 0.4 - 1 | Churchill; St. John's | $10^{-5}$ |
| Natural Radioactivity in Drinking Water ($^{226}Ra$, U) | $2 \times 10^{-3}$ - $1 \times 10^{-2}$ | Saskatoon; Regina | $10^{-7}$ |
| Fission Products in Drinking Water ($^{90}Sr$, $^{137}Cs$) | $4 \times 10^{-4}$ - $1 \times 10^{-3}$ | St. Lawrence River; Winnipeg River | $10^{-8}$ |
| Fission Products in Milk ($^{90}Sr$, $^{137}Cs$) | $2 \times 10^{-5}$ - $5 \times 10^{-4}$ | Montreal; St. John's | $10^{-9}$ |
| Tritium in Atmospheric Water Vapour | $1 \times 10^{-5}$ - $2 \times 10^{-3}$ | Gentilly, Bruce, Pickering | $10^{-8}$ |

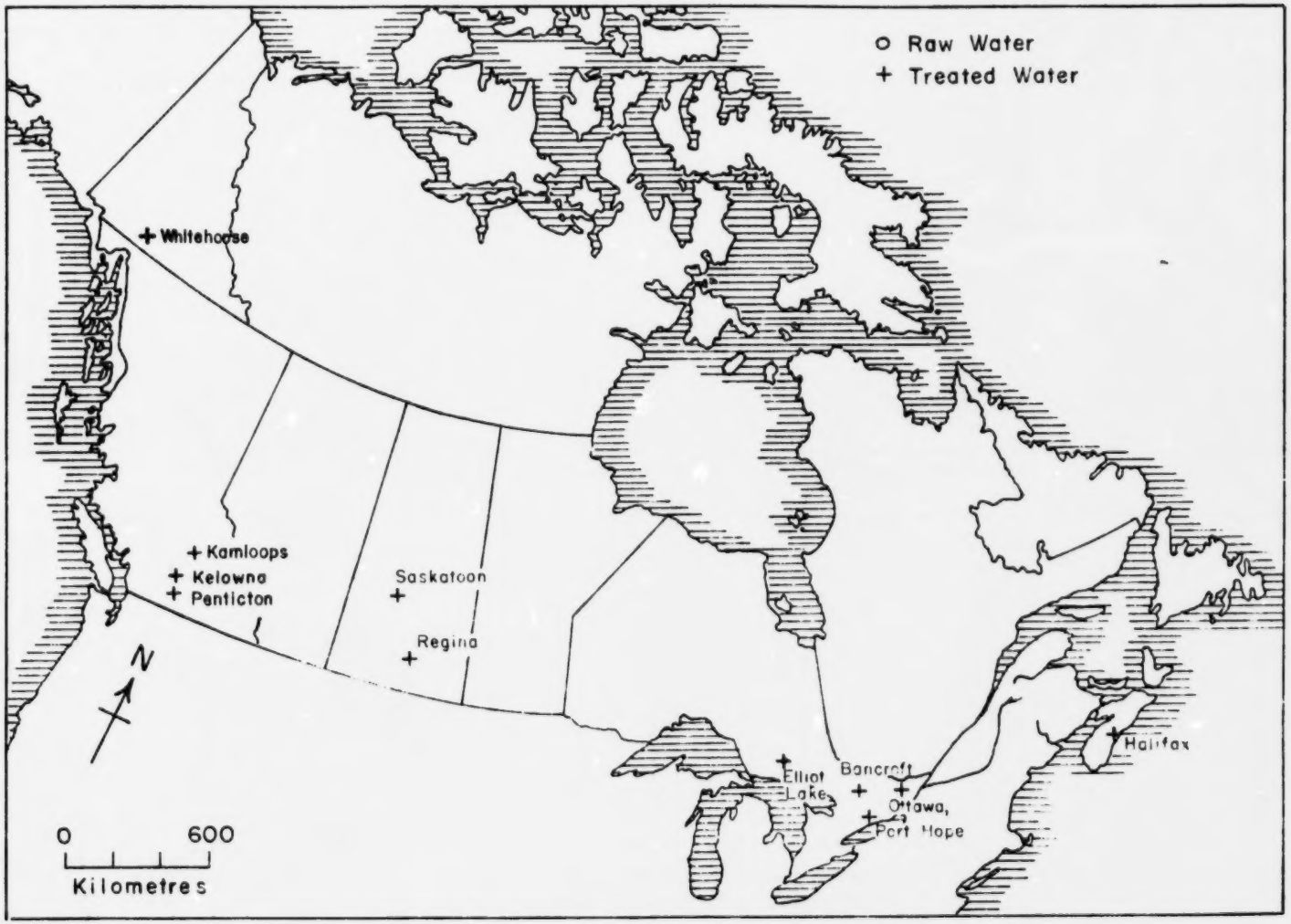



Figure 1. Canadian Sampling Station Network - Drinking Water

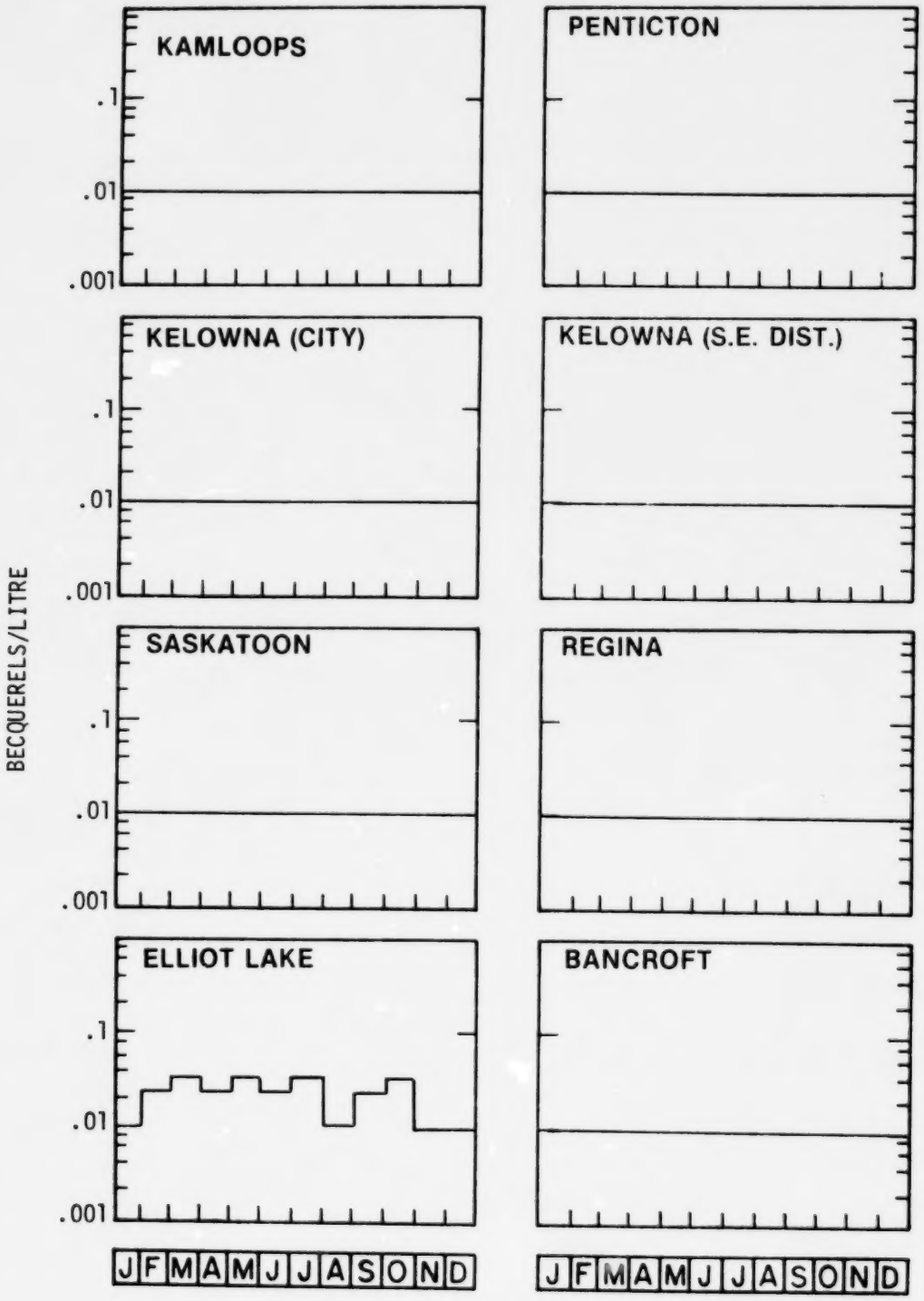



Figure 2(a). Radium-226 Levels in Drinking Water, 1980
(Detection Limit is 0.01 Bq/L)

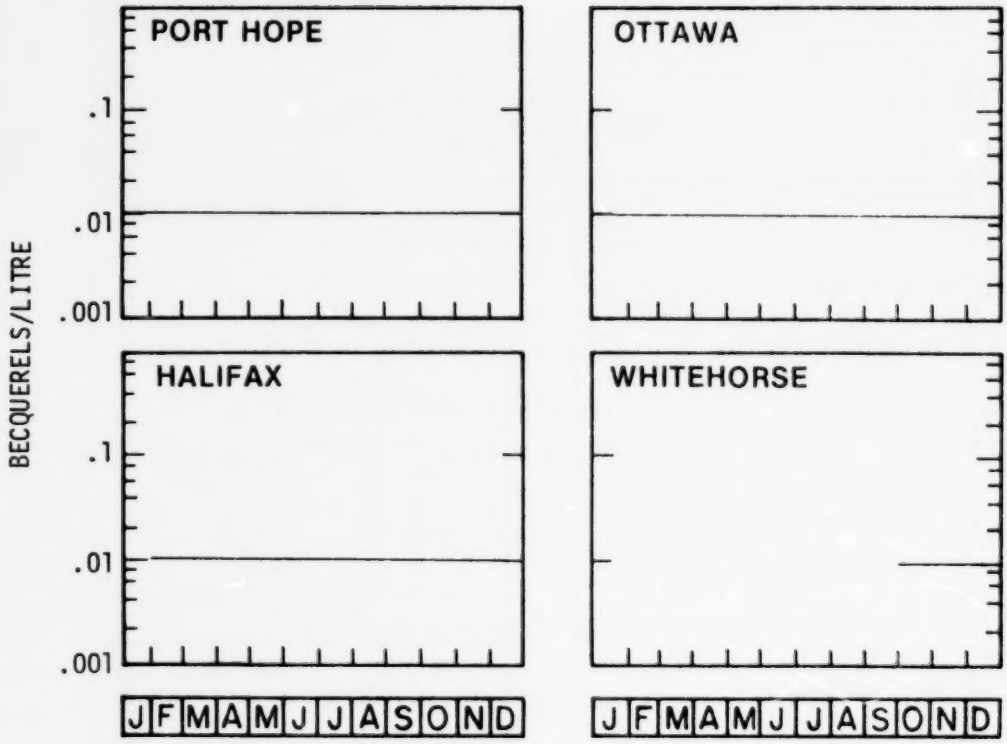



Figure 2(b). Radium-226 Levels in Drinking Water, 1980
(Detection Limit is 0.01 Bq/L)

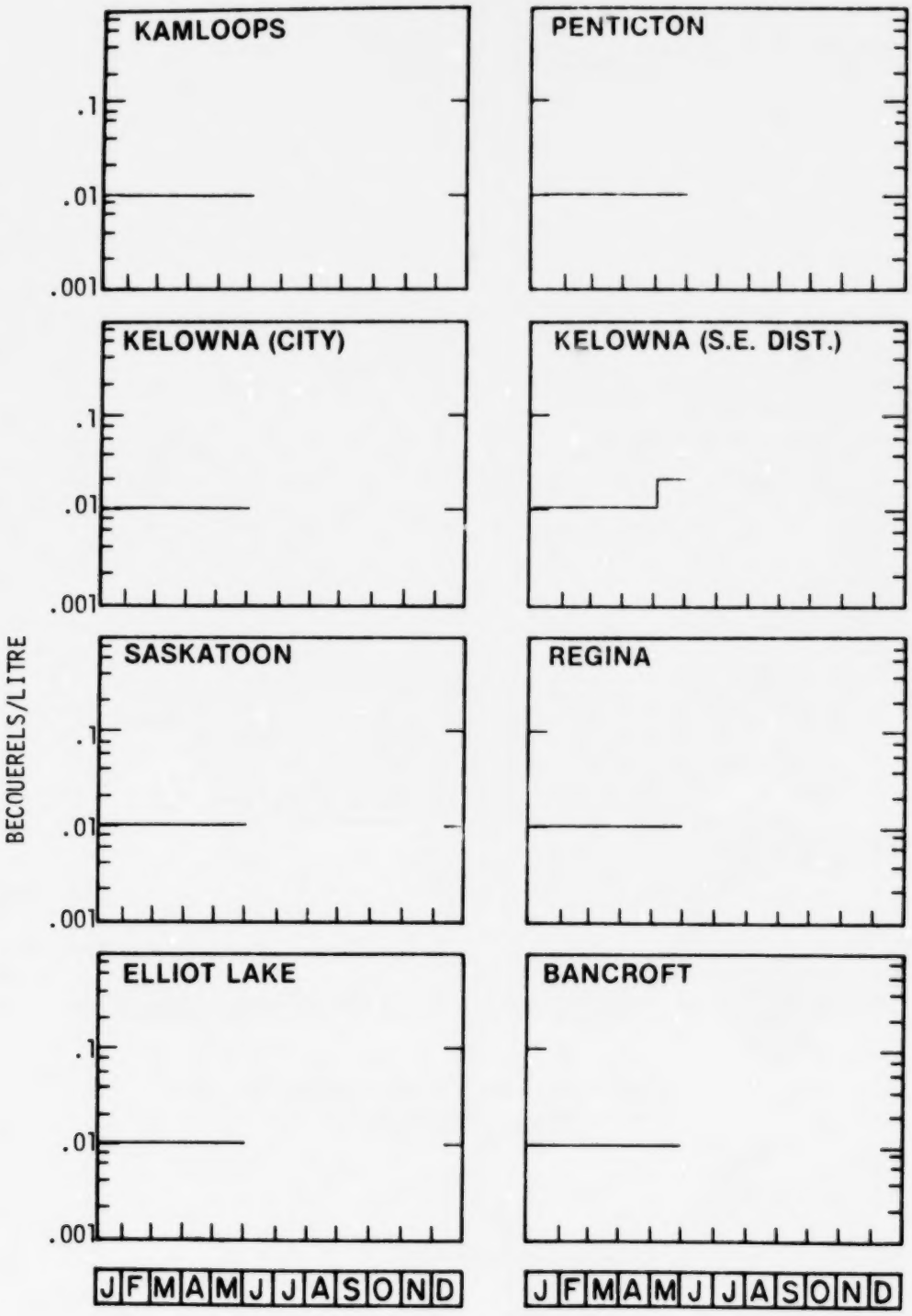



Figure 3(a). Lead-210 Levels in Drinking Water, 1980
(Detection Limit is 0.01 Bq/L)

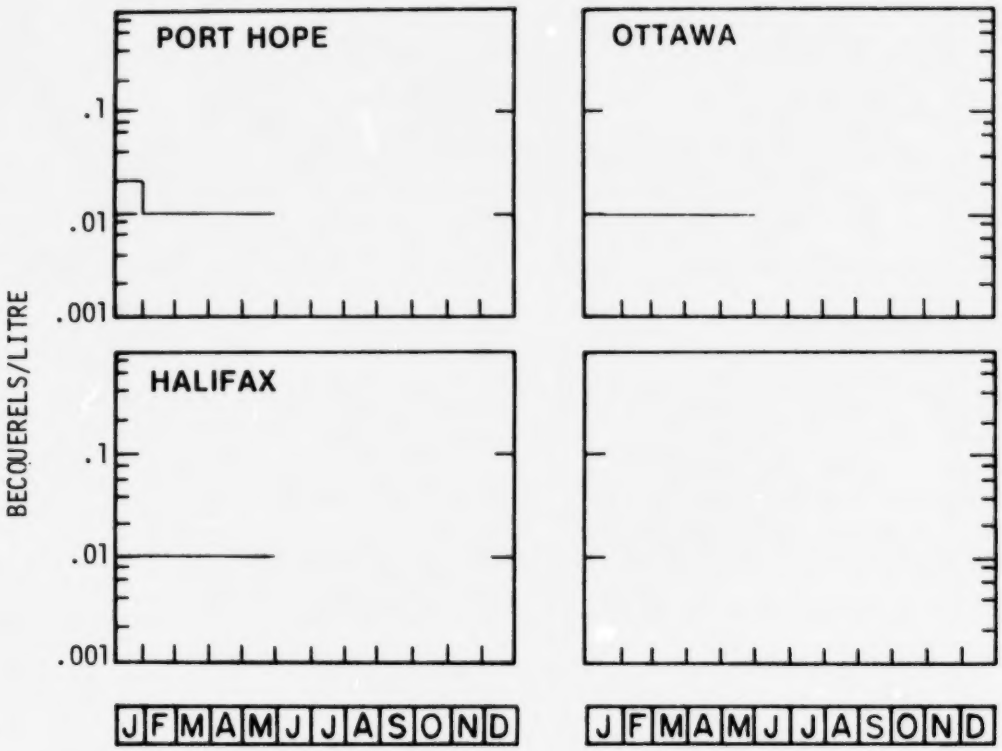



Figure 3(b). Lead-210 Levels in Drinking Water, 1980
(Detection Limit is 0.01 Bq/L)

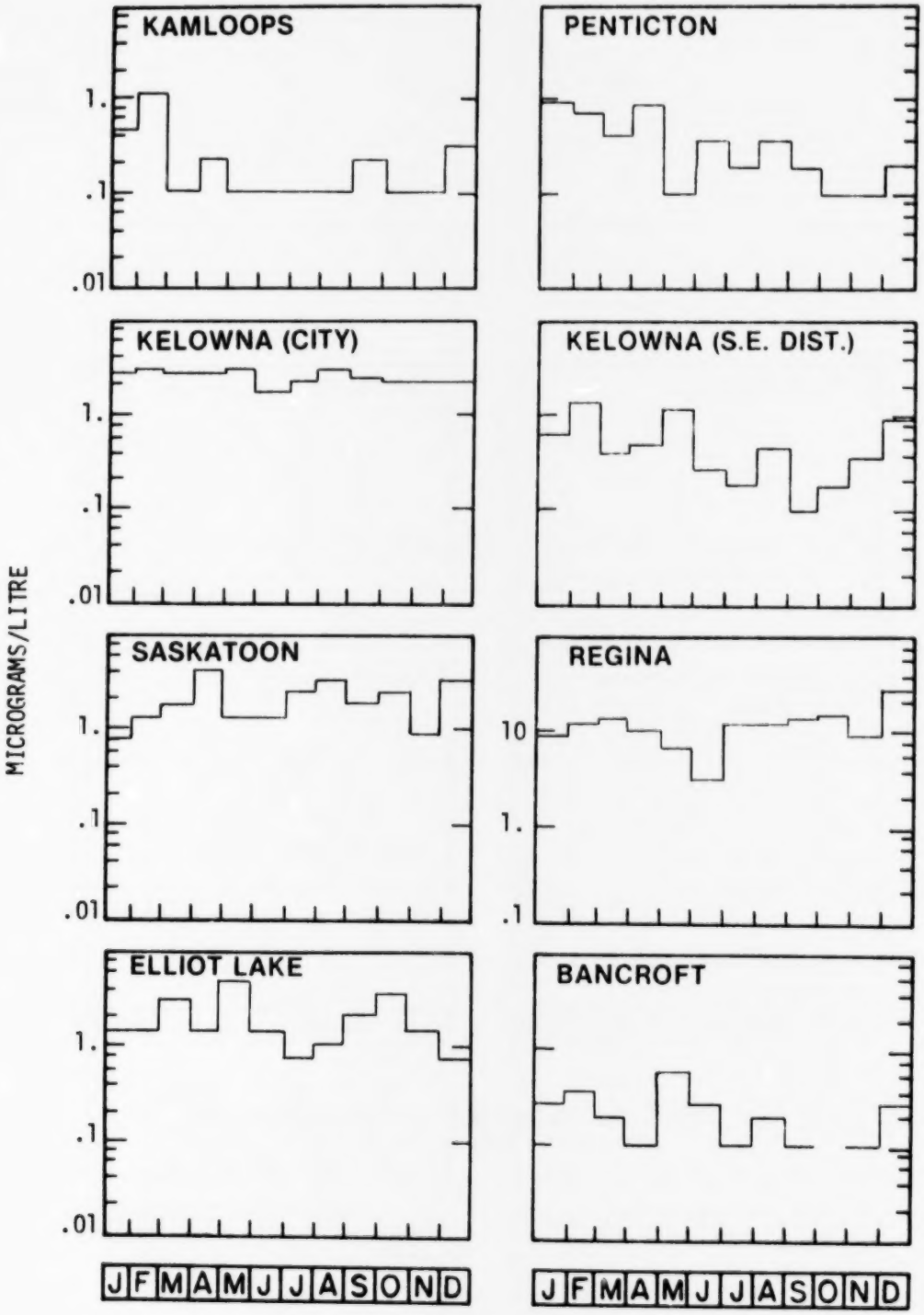



Figure 4(a). Uranium Levels in Drinking Water, 1980
(Detection Limit is 0.1 µg/L)

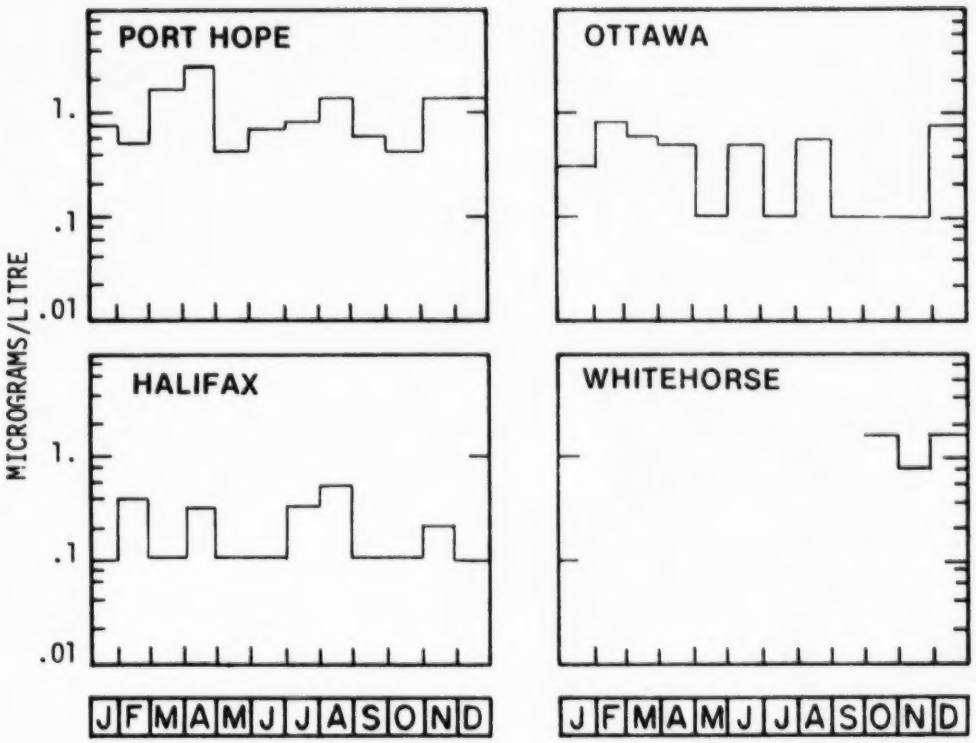



Figure 4(b). Uranium Levels in Drinking Water, 1980
(Detection Limit is 0.1 µg/L)

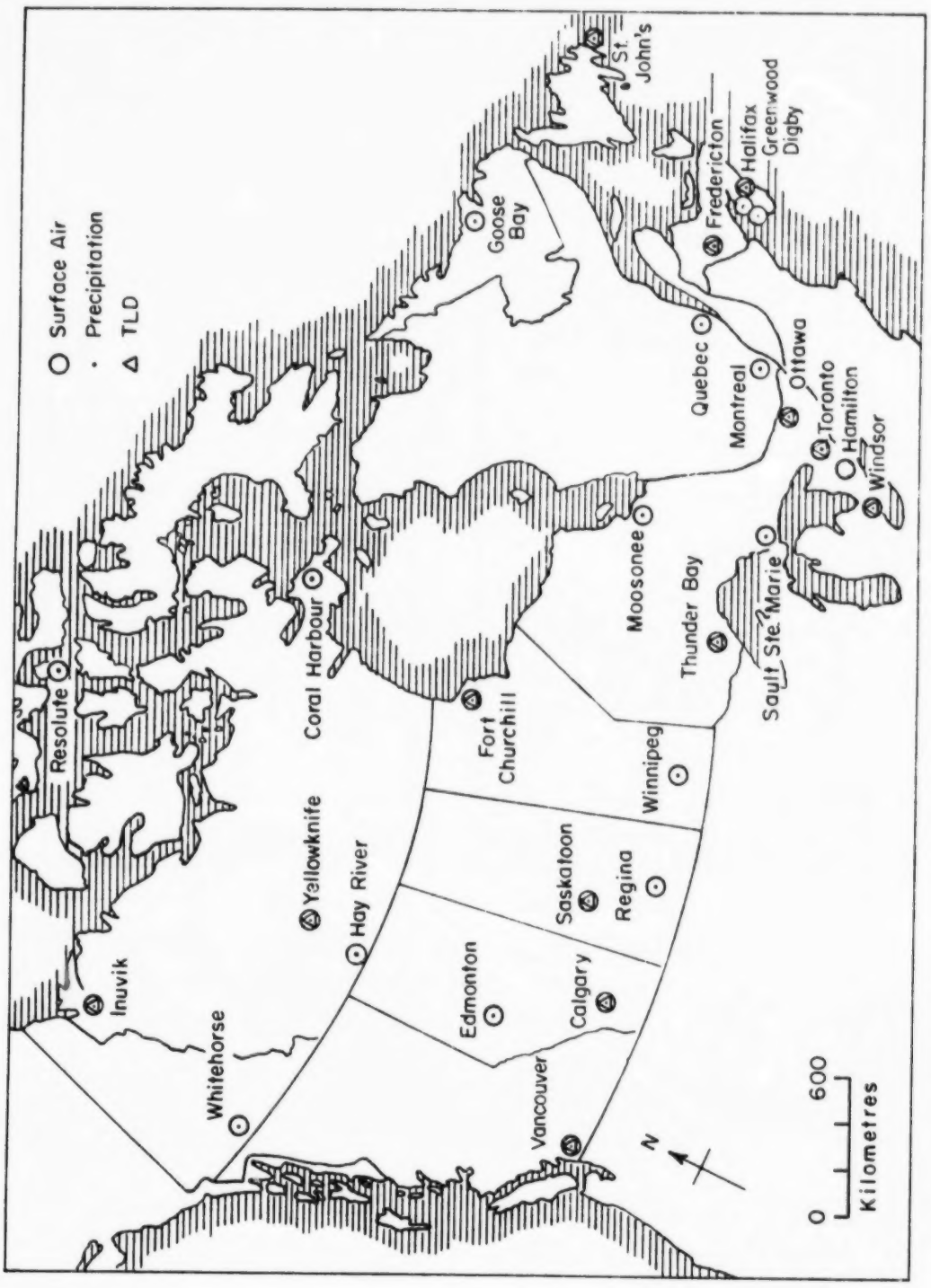



Figure 5. Canadian Sampling Station Network - Air, Precipitation and TLD

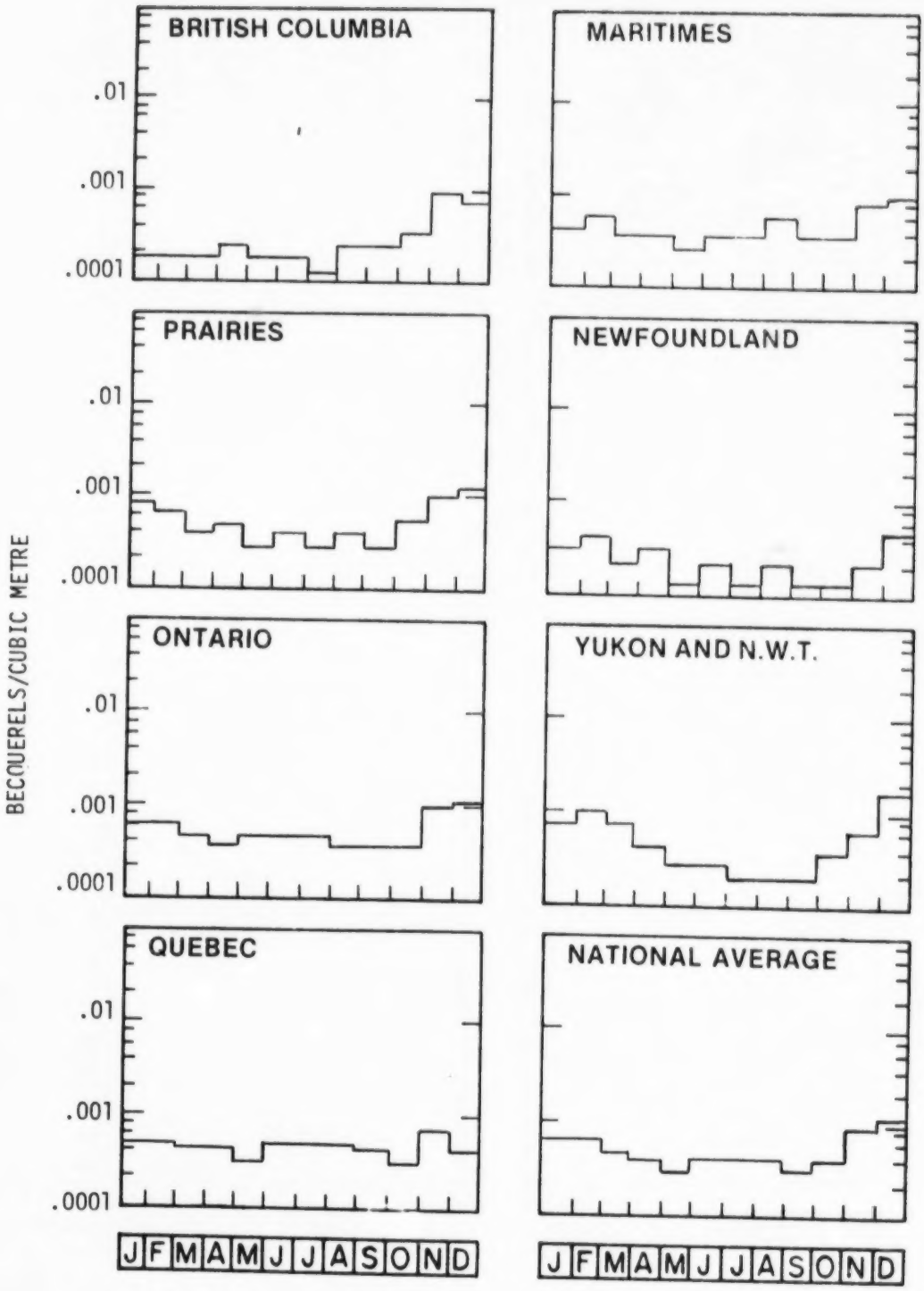



Figure 6. Gross Beta Radioactivity in Surface Air, 1980
(Detection Limit is 0.0001 Bq/m$^3$)

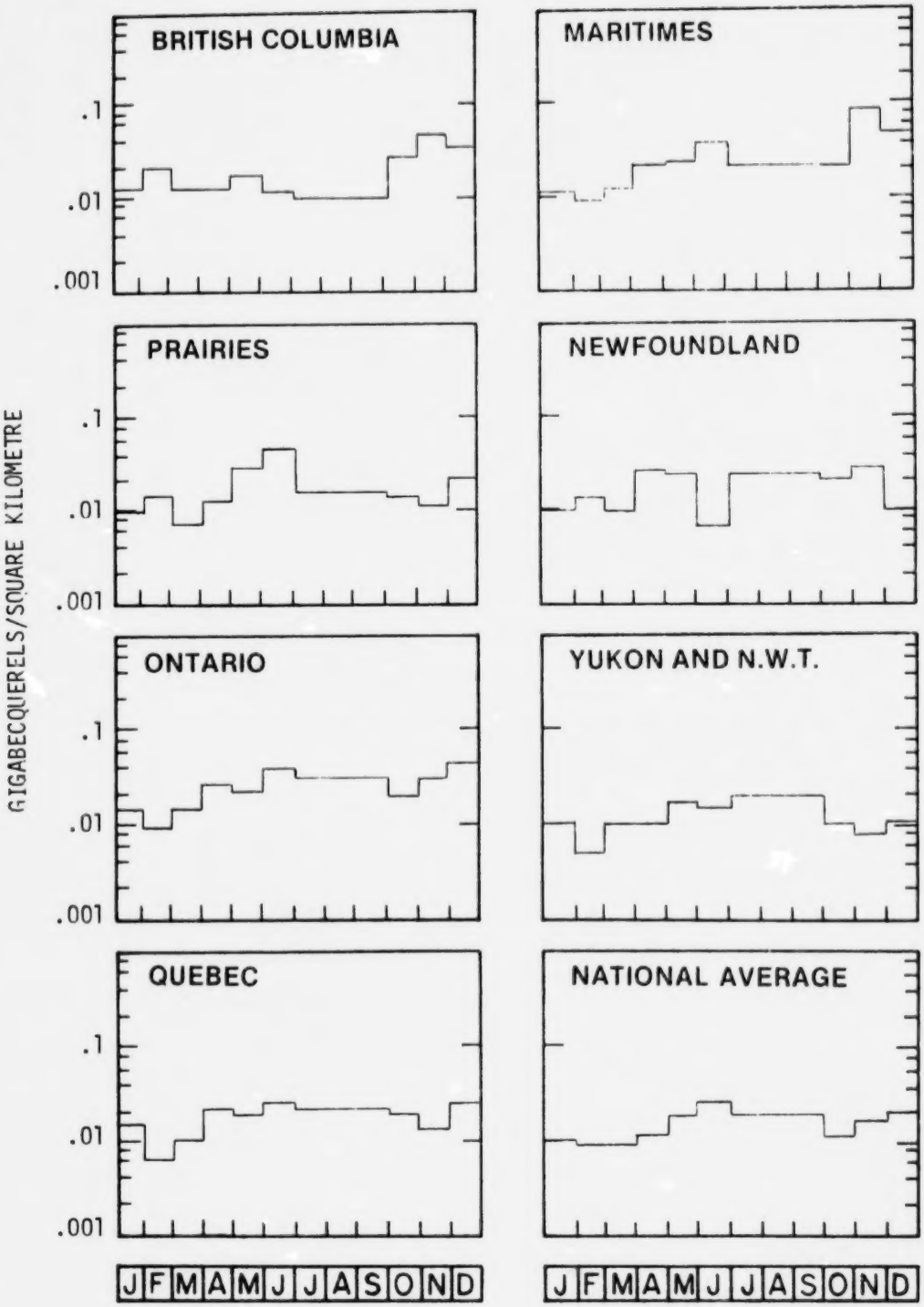



Figure 7. Gross Beta Radioactivity in Precipitation, 1980
(Detection Limit is 0.004 GBq/km$^2$)

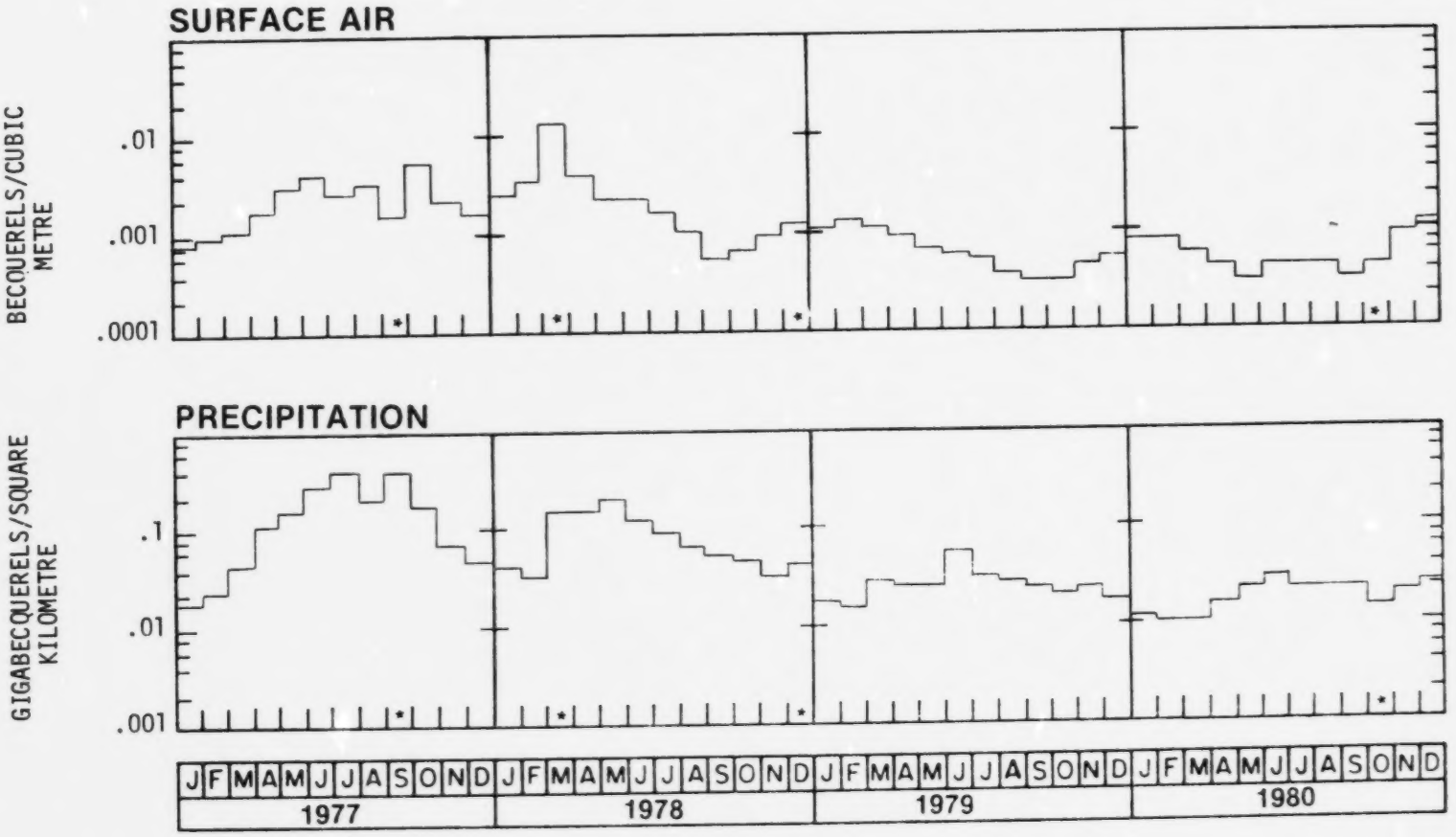

SURFACE AIR
BECQUERELS/CUBIC METRE
.01
.001
.0001
PRECIPITATION
GIGABECQUERELS/SQUARE KILOMETRE
.1
.01
.001
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1977
1978
1979
1980

Figure 8. Gross Beta Radioactivity, National Averages 1977-1980

* Atmospheric Nuclear Weapons Tests Conducted by the People's Republic of China at Lop Nor

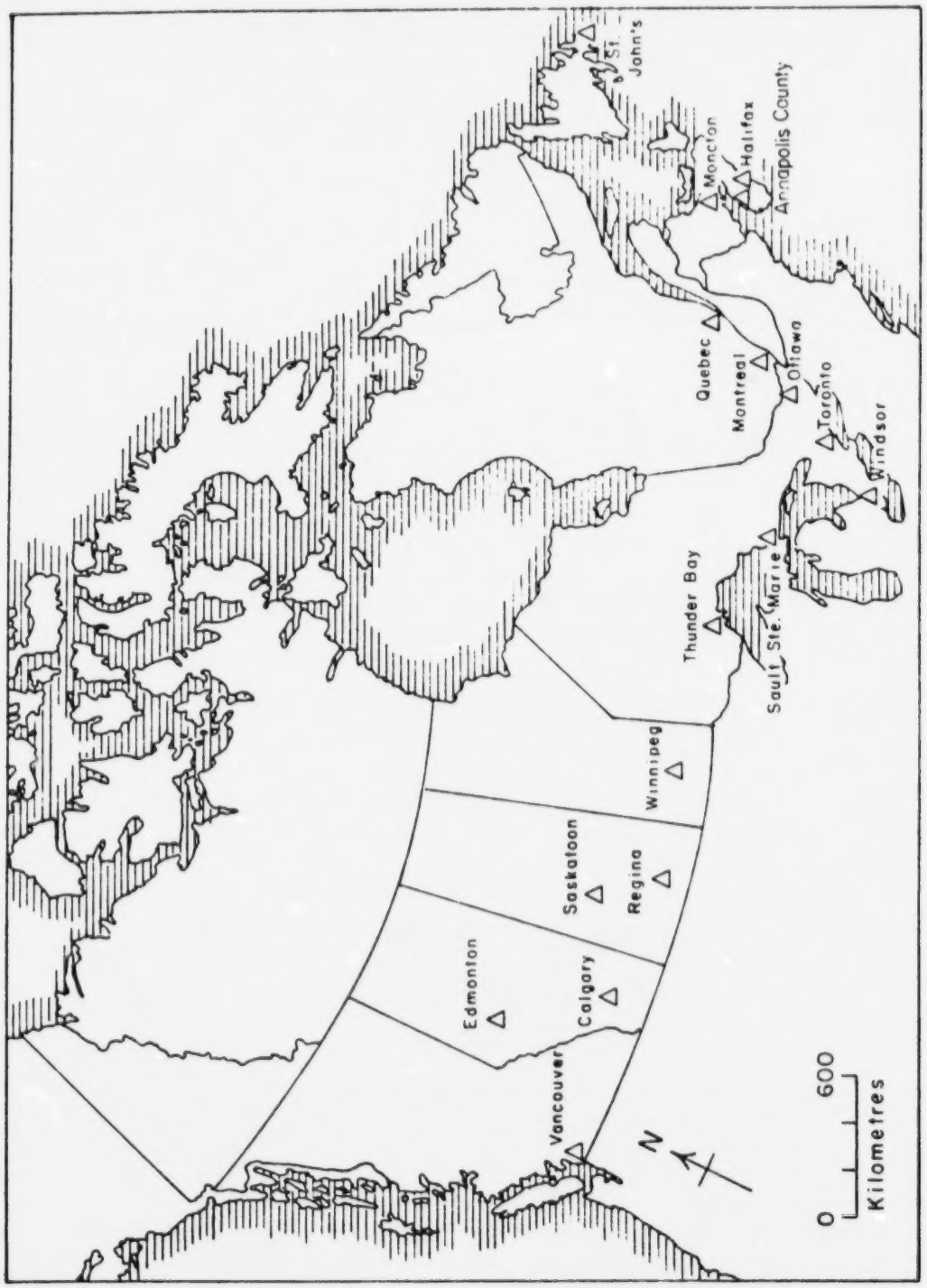



Figure 9. Canadian Sampling Station Network - Milk

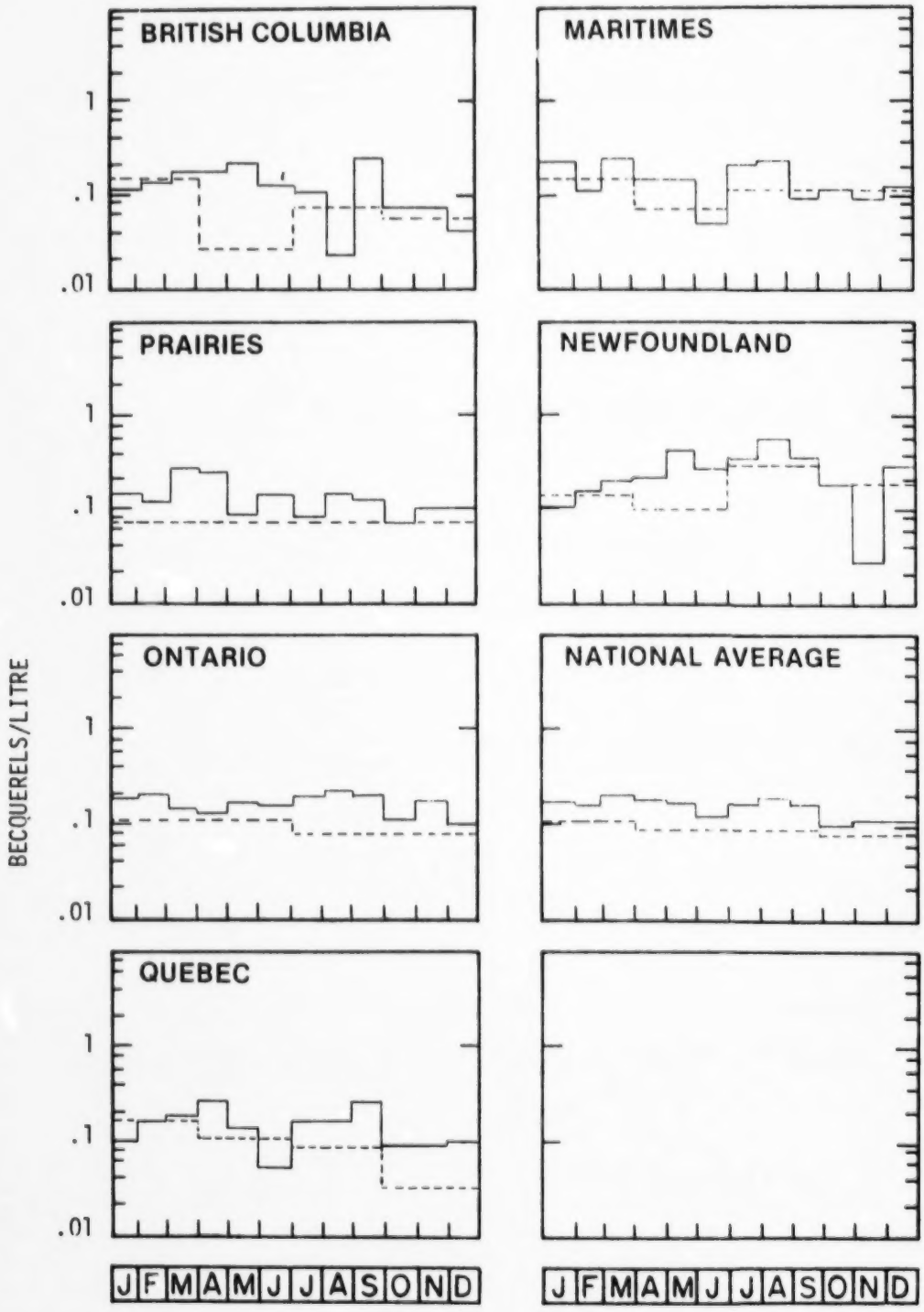



Figure 10. Fallout Radioactivity Levels in Whole Milk, 1980

_____ Cesium-137 -------- Strontium-90

(Detection Limits are 0.04 Bq/L, Cesium-137 and 0.001 Bq/L, Strontium-90)

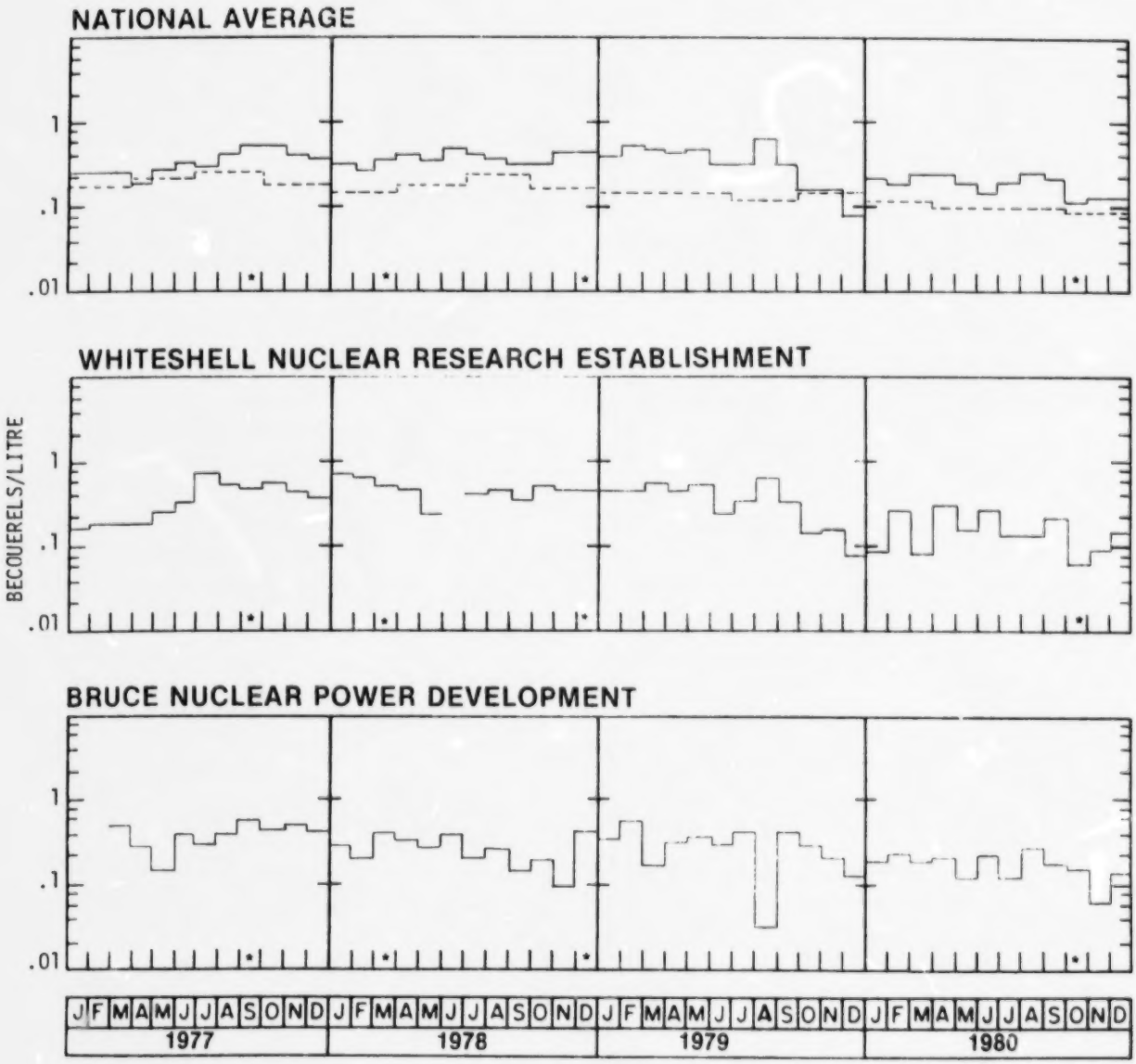

NATIONAL AVERAGE
WHITESHELL NUCLEAR RESEARCH ESTABLISHMENT
BRUCE NUCLEAR POWER DEVELOPMENT
BECQUERELS/LITRE
1
.1
.01
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1977
1978
1979
1980

Figure 11. Radionuclide Levels in Milk, 1977-1980

_____ Cesium-137 -------- Strontium-90

* Astmospheric Nuclear Weapons Tests Conducted by People's Republic of China

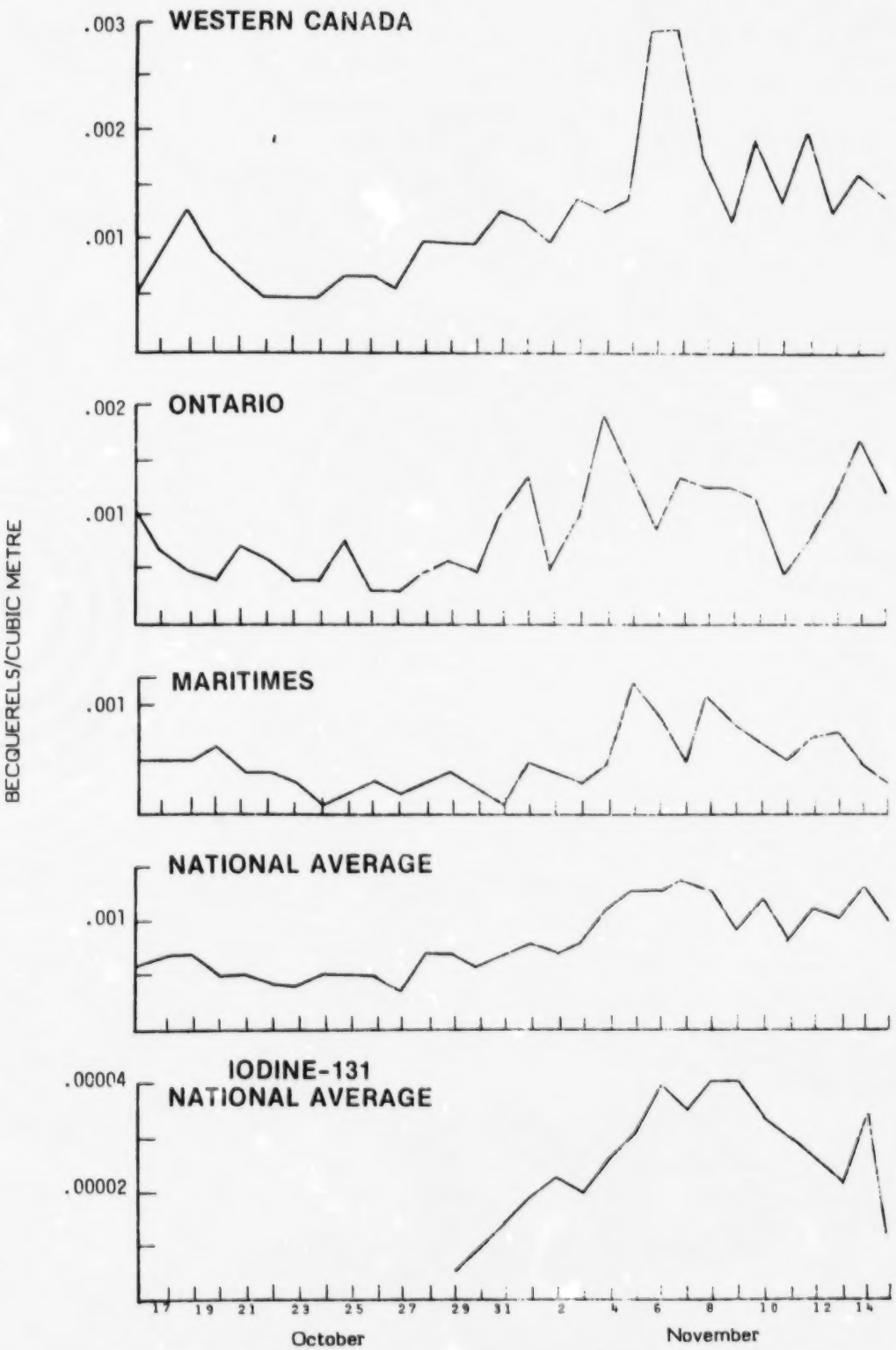



Figure 12. Gross Beta and Iodine-131 Activity in Surface Air Following the Nuclear Weapons Test of October 16, 1980

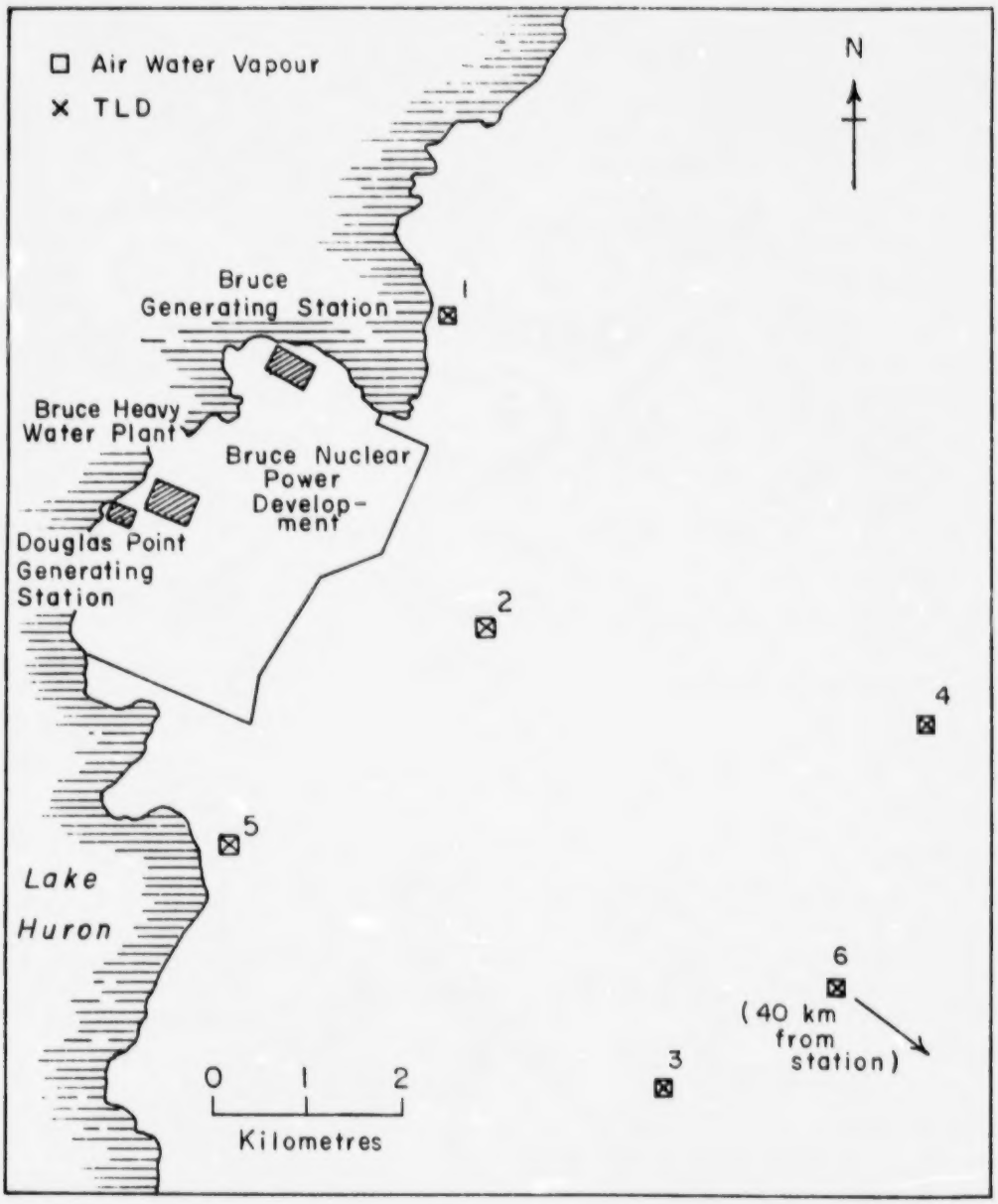



Figure 13. Sampling Stations in the Vicinity of the Bruce Nuclear Power Development

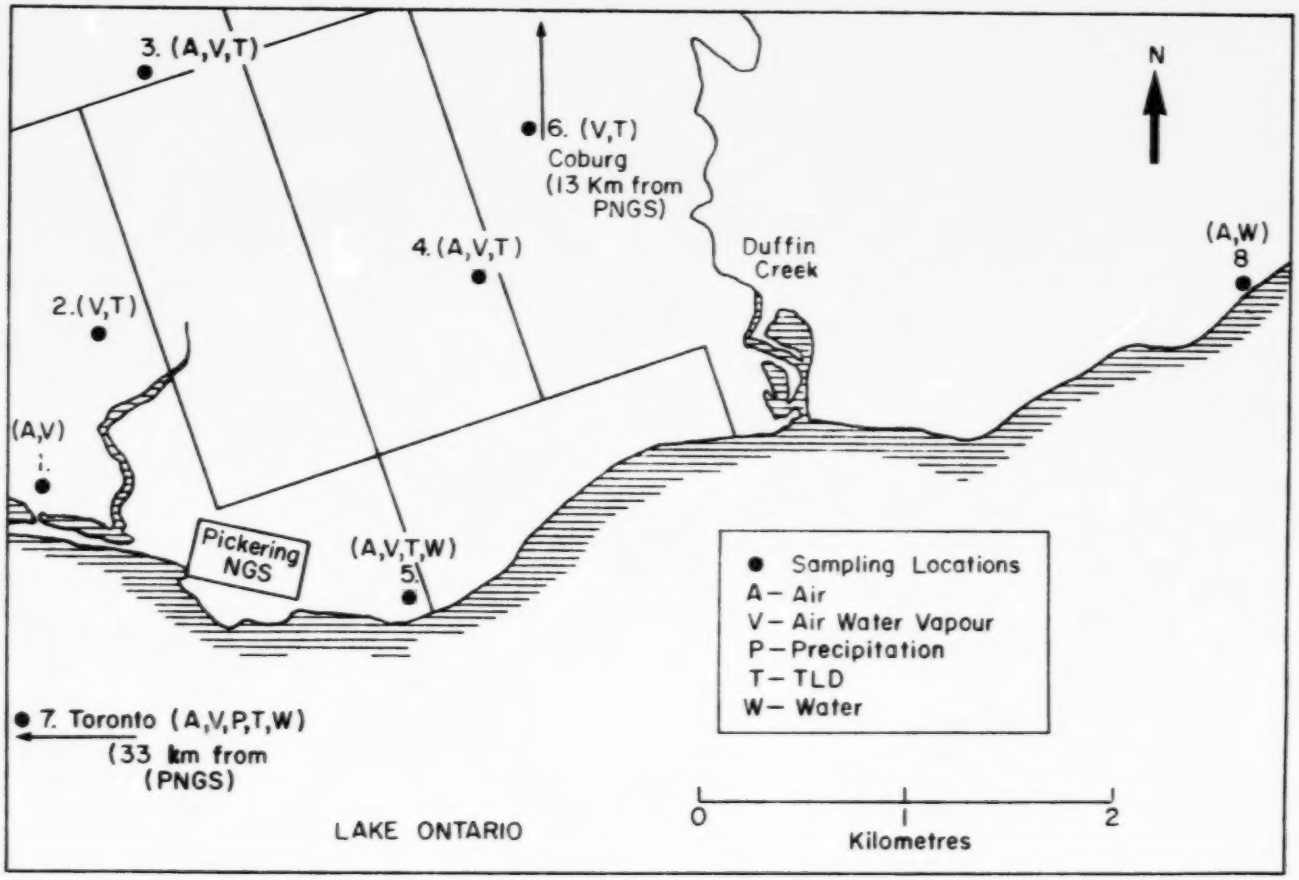
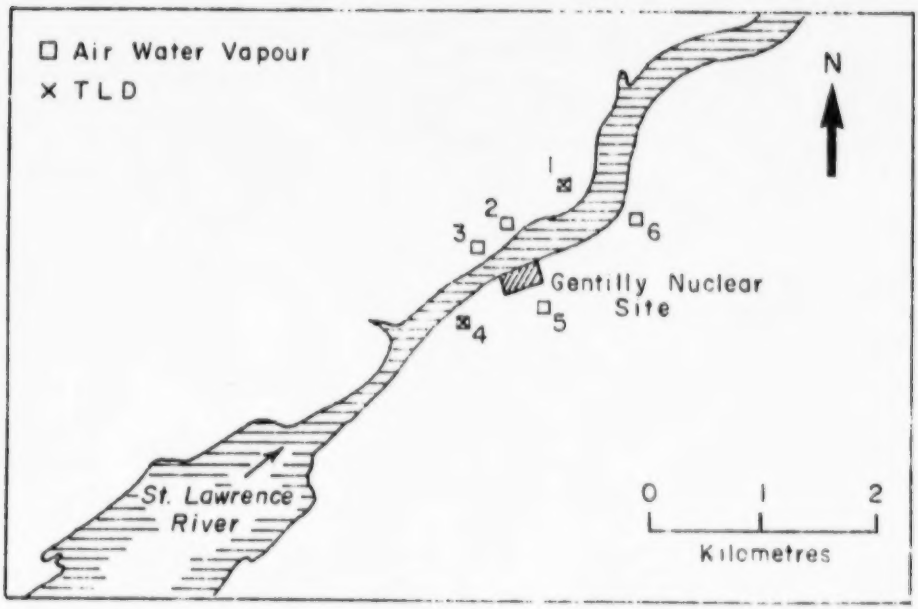



Figure 14. Sampling Stations in the Vicinity of the Pickering Nuclear Generating Station



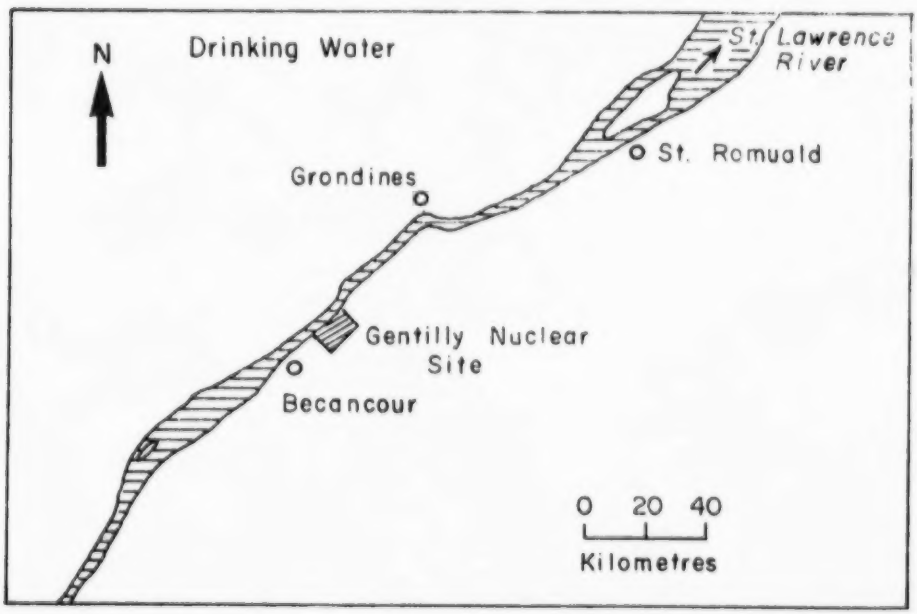




Figure 15. Sampling Stations in the Vicinity of the Gentilly Nuclear Site

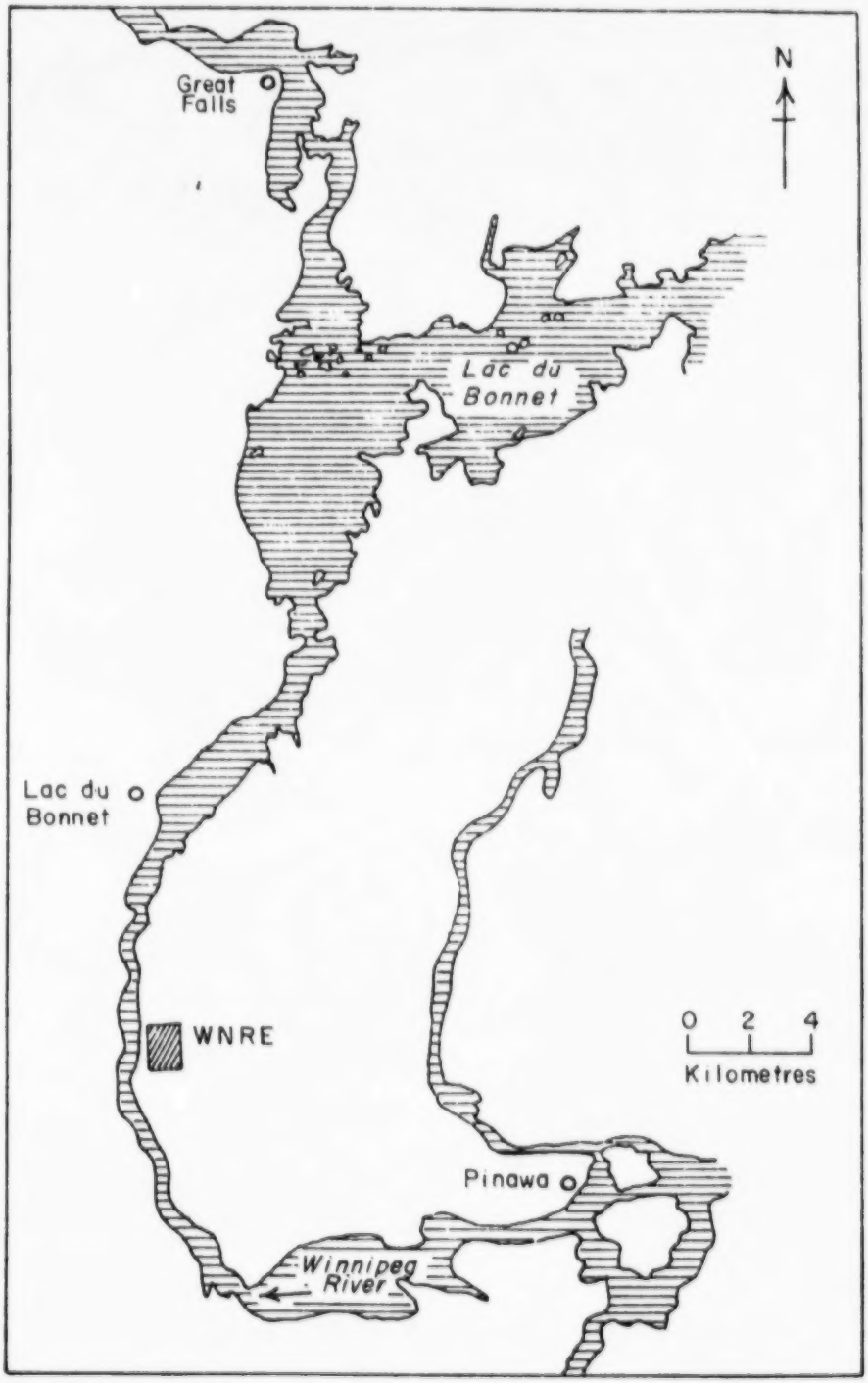



Figure 16. Sampling Locations on the Winnipeg River - Drinking Water

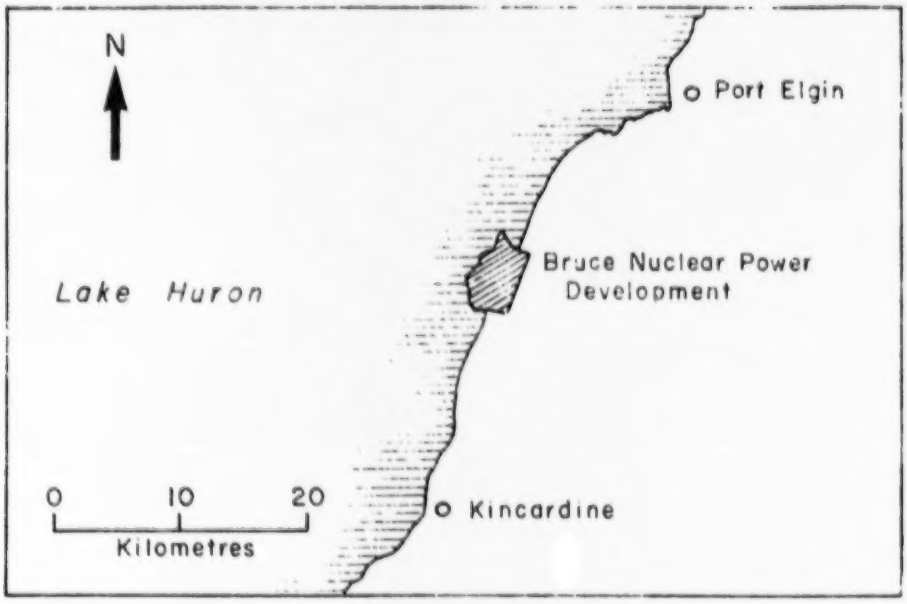



Figure 17. Sampling Locations on Lake Huron - Drinking Water

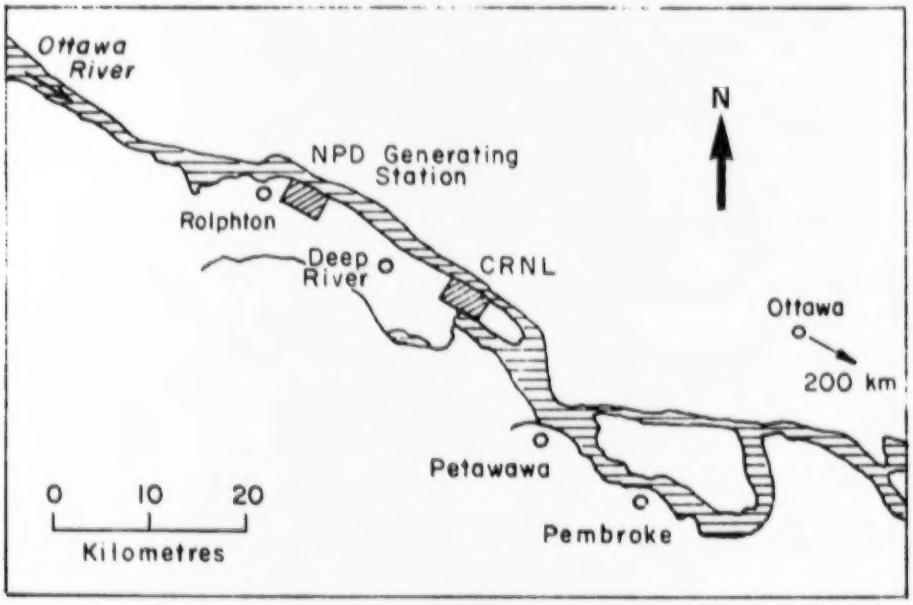



Figure 18. Sampling Locations on the Ottawa River - Drinking Water

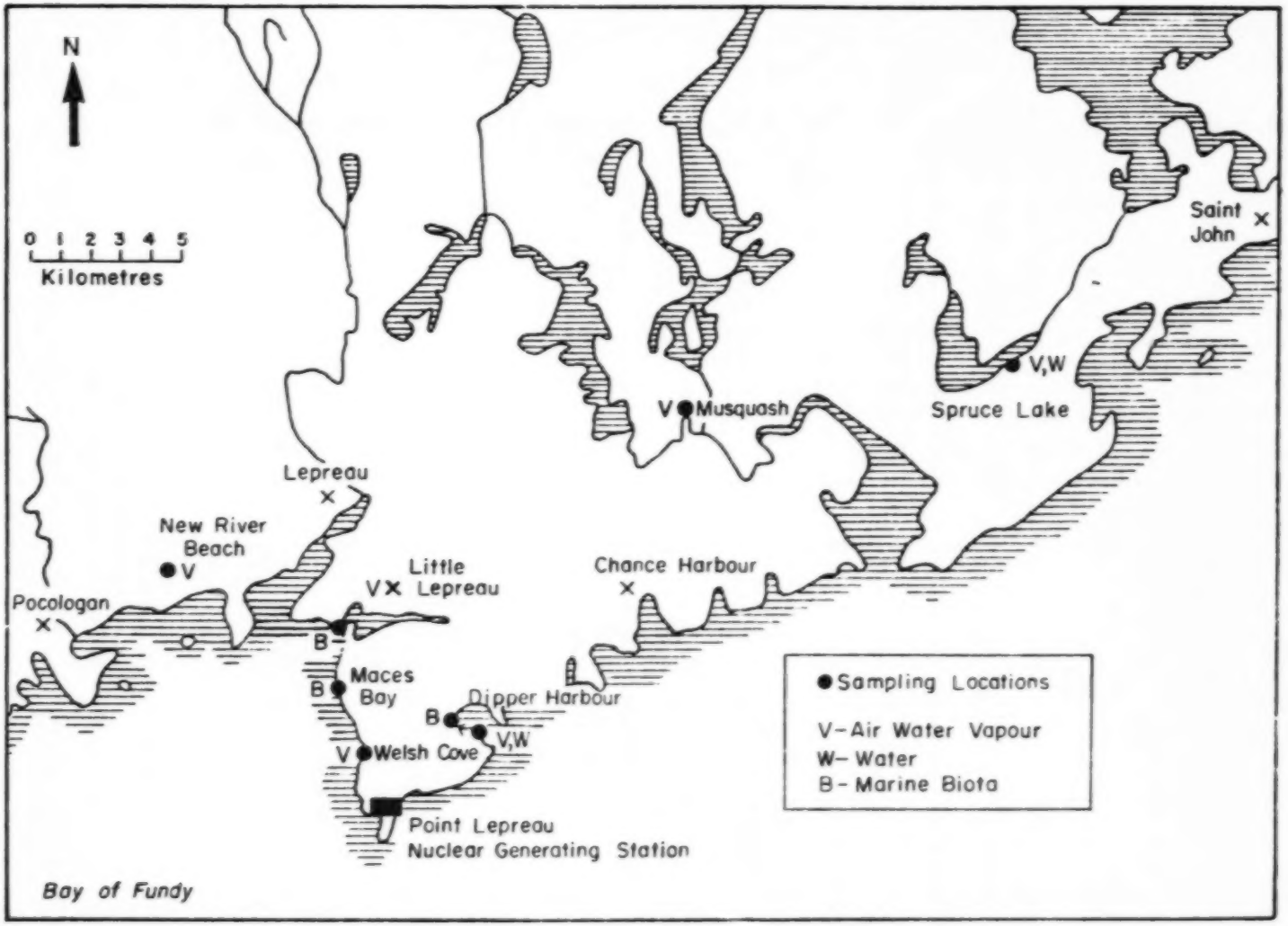



Figure 19. Sampling Locations in the Vicinity of the Point Lepreau Nuclear Generating Station

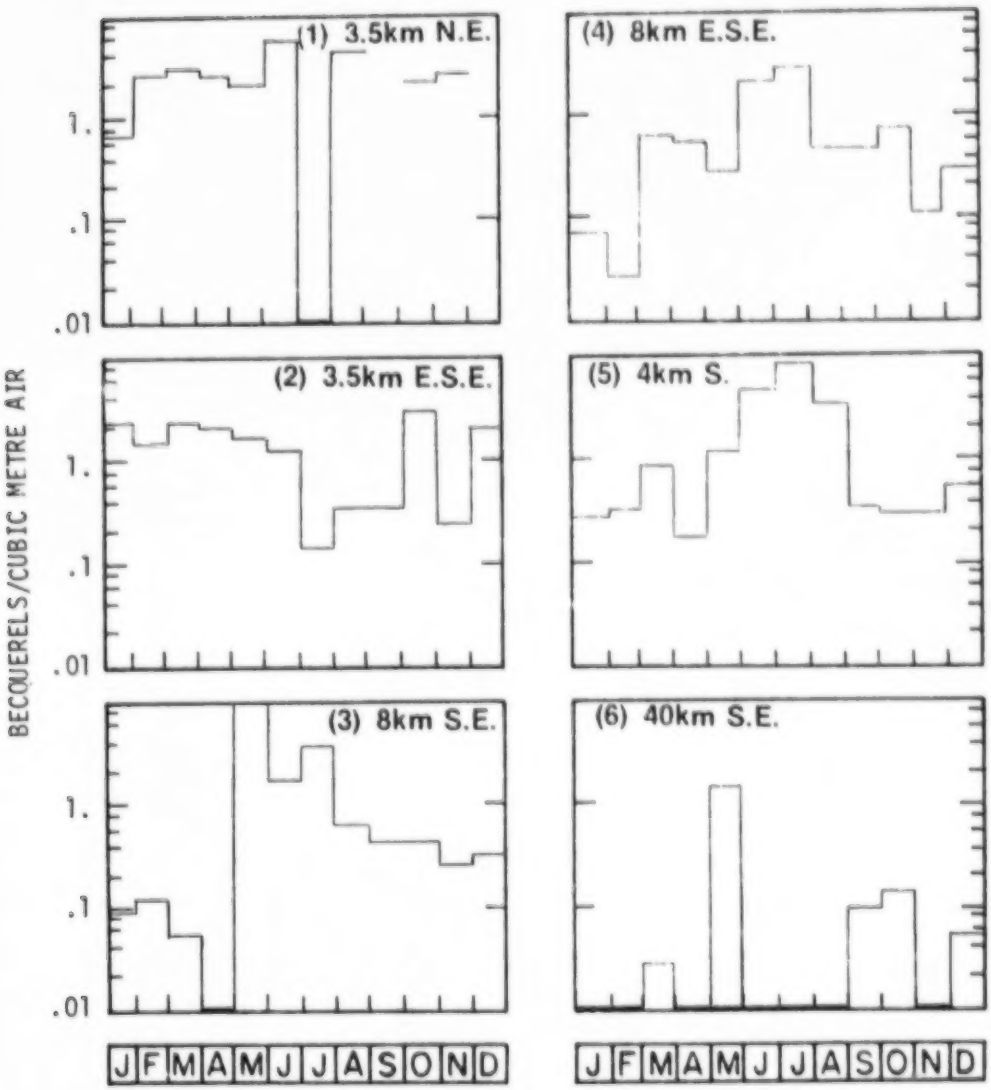



Figure 20. Tritium Levels Near the Bruce Nuclear Power Development, 1980
(Detection Limit is 0.01 Bq/$m^3$)

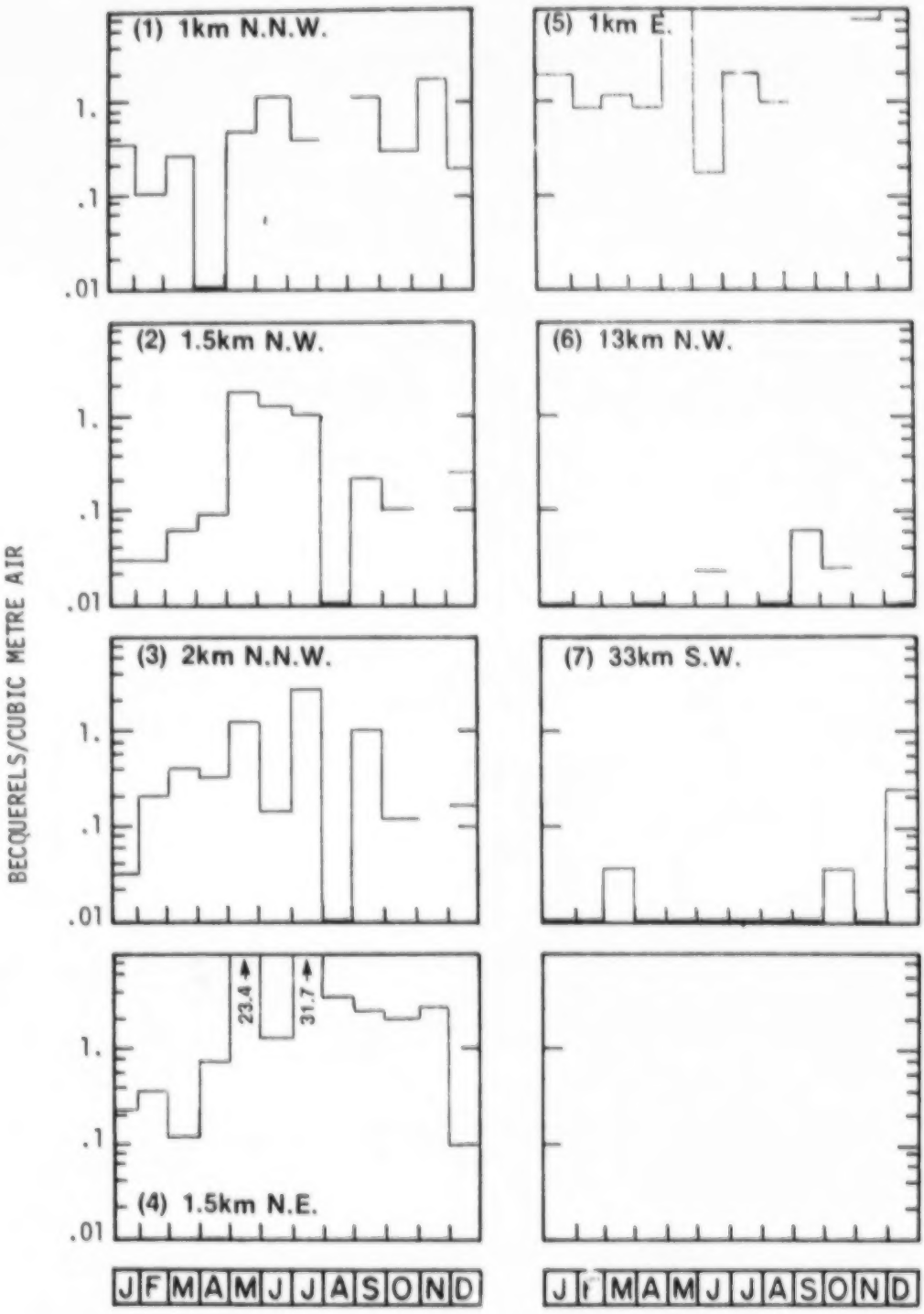



Figure 21. Tritium Levels near the Pickering Nuclear Generating Station, 1980
(Detection Limit is 0.01 Bq/$m^3$)

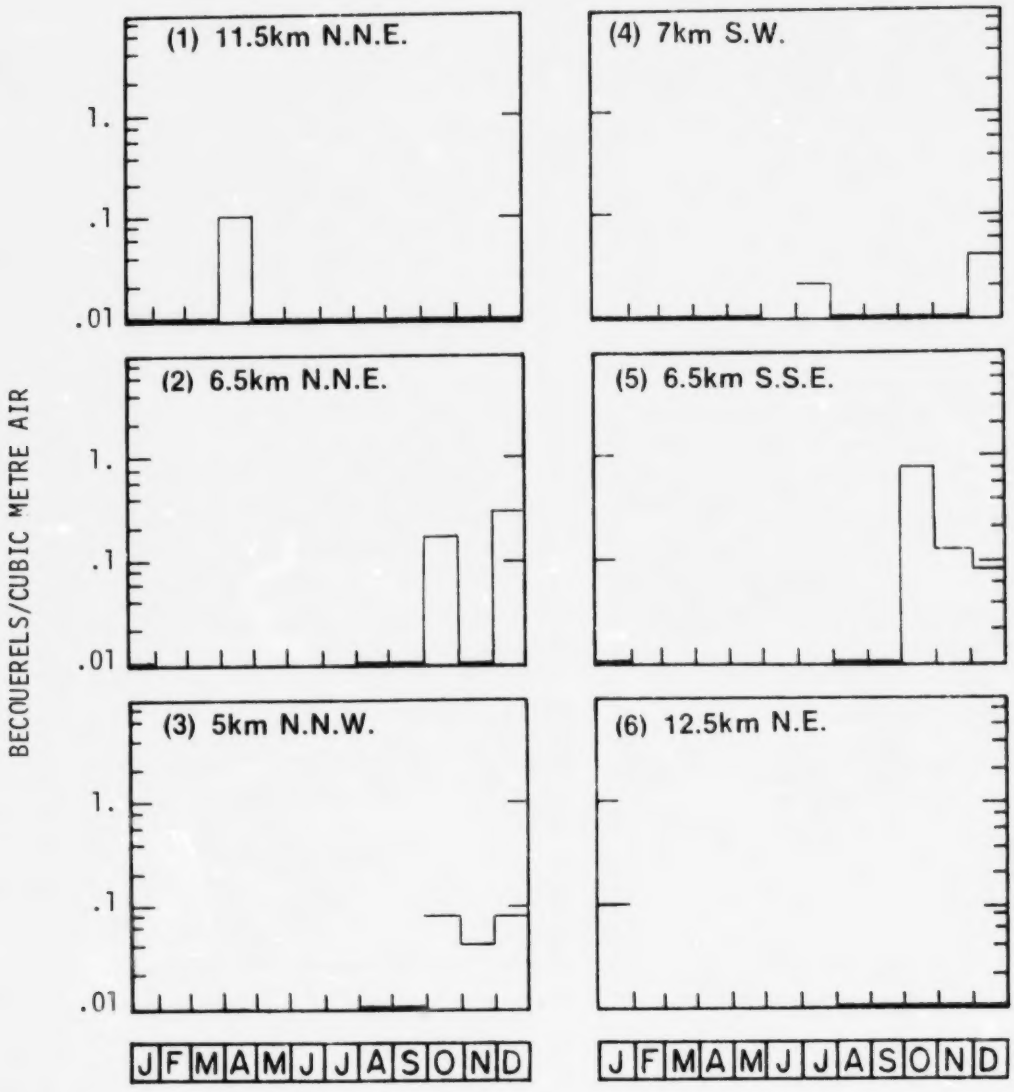



Figure 22. Tritium Levels Near the Gentilly Nuclear Site, 1980
(Detection Limit is 0.01 Bq/m$^3$)

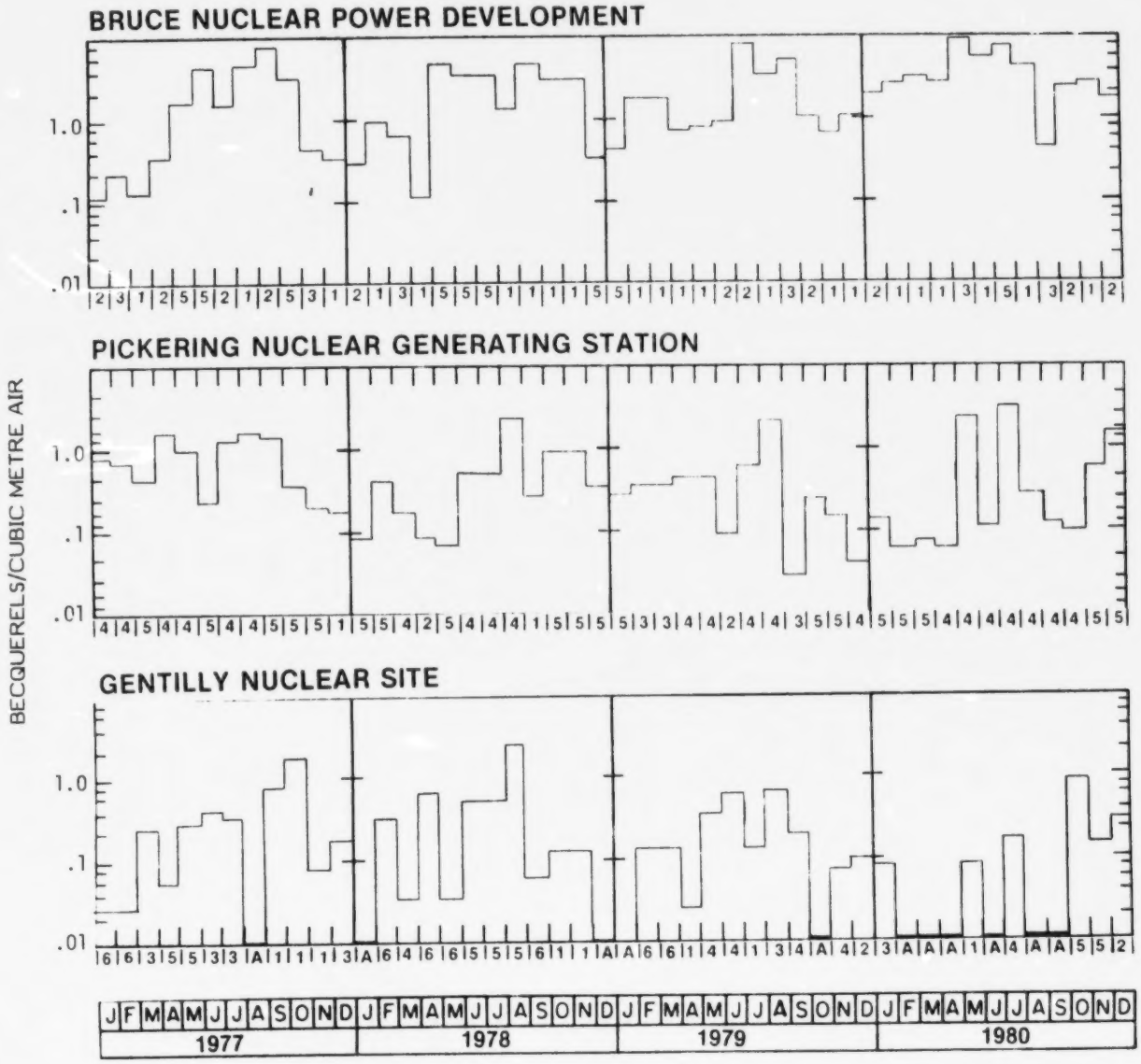

BRUCE NUCLEAR POWER DEVELOPMENT
PICKERING NUCLEAR GENERATING STATION
GENTILLY NUCLEAR SITE
BECQUERELS/CUBIC METRE AIR
1.0
.1
.01
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1977
1978
1979
1980

Figure 23. Highest Tritium Levels around Nuclear Power Stations in Canada 1977-1980
(Detection Limit is 0.01 Bq/m$^3$)

(Numbers beneath the graphs indicate the station at which the measurements were made. A = All Stations)

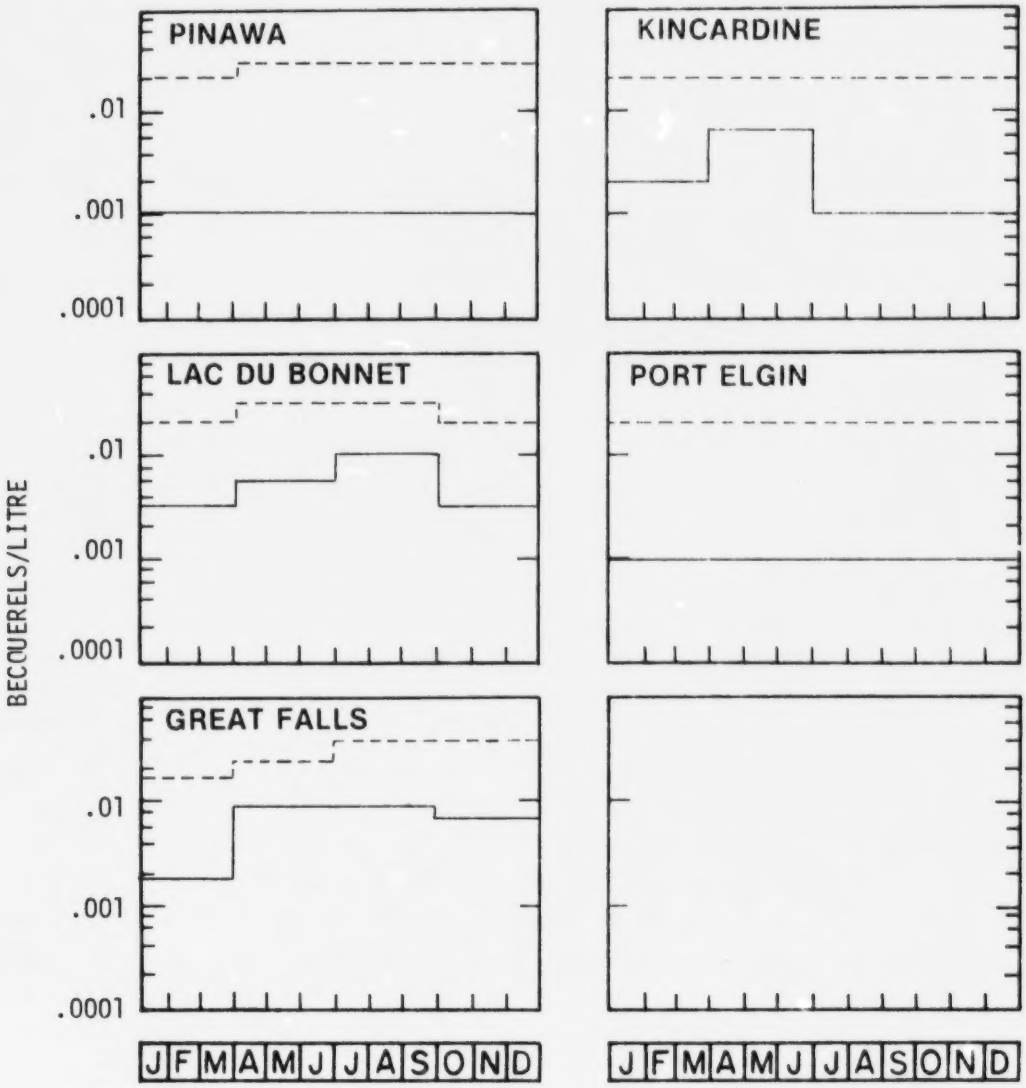



Figure 24. Radionuclides in the Winnipeg River and Lake Huron, 1980

_____ Cesium-137 -------- Strontium-90

(Detection Limit is 0.001 Bq/L, Cesium-137 and Strontium-90)

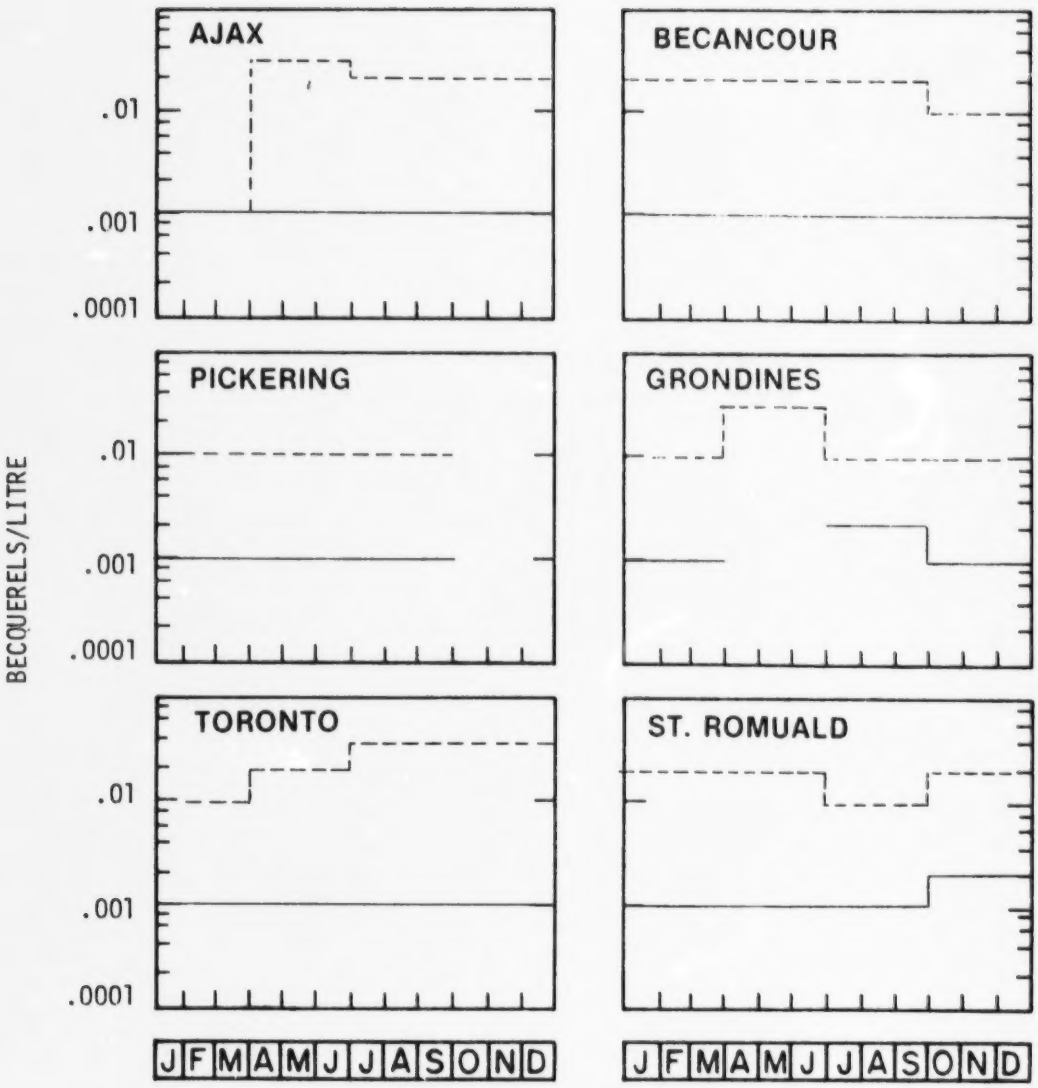



Figure 25. Radionuclides in Lake Ontario and the St. Lawrence River, 1980

_____ Cesium-137 -------- Strontium-90

(Detection Limit is 0.001 Bq/L, Cesium-137 and Strontium-90)

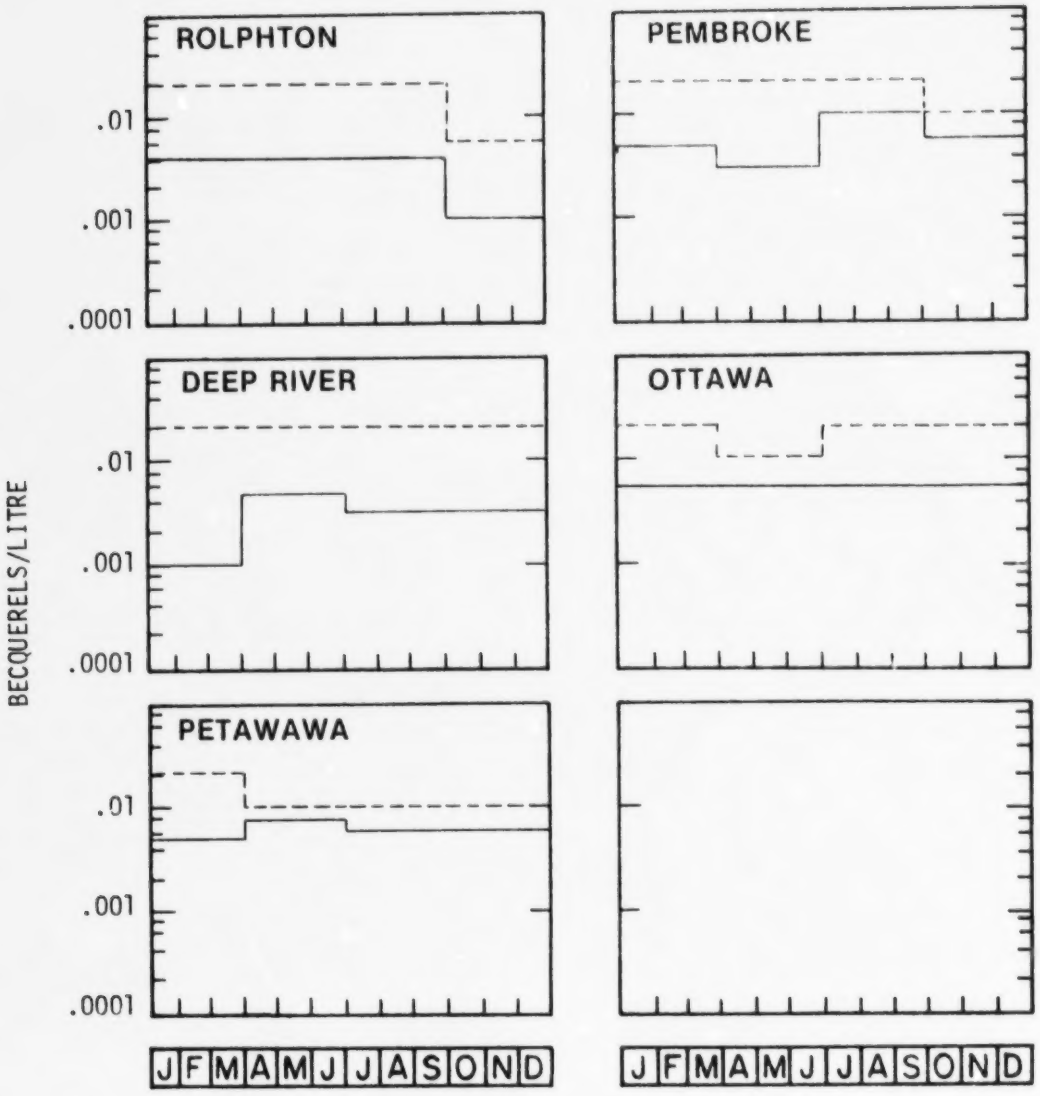



Figure 26. Radionuclides in the Ottawa River, 1980

_____ Cesium-137 --------Strontium-90

(Detection Limit is 0.001 Bq/L,
Cesium-137 and Strontium-90)

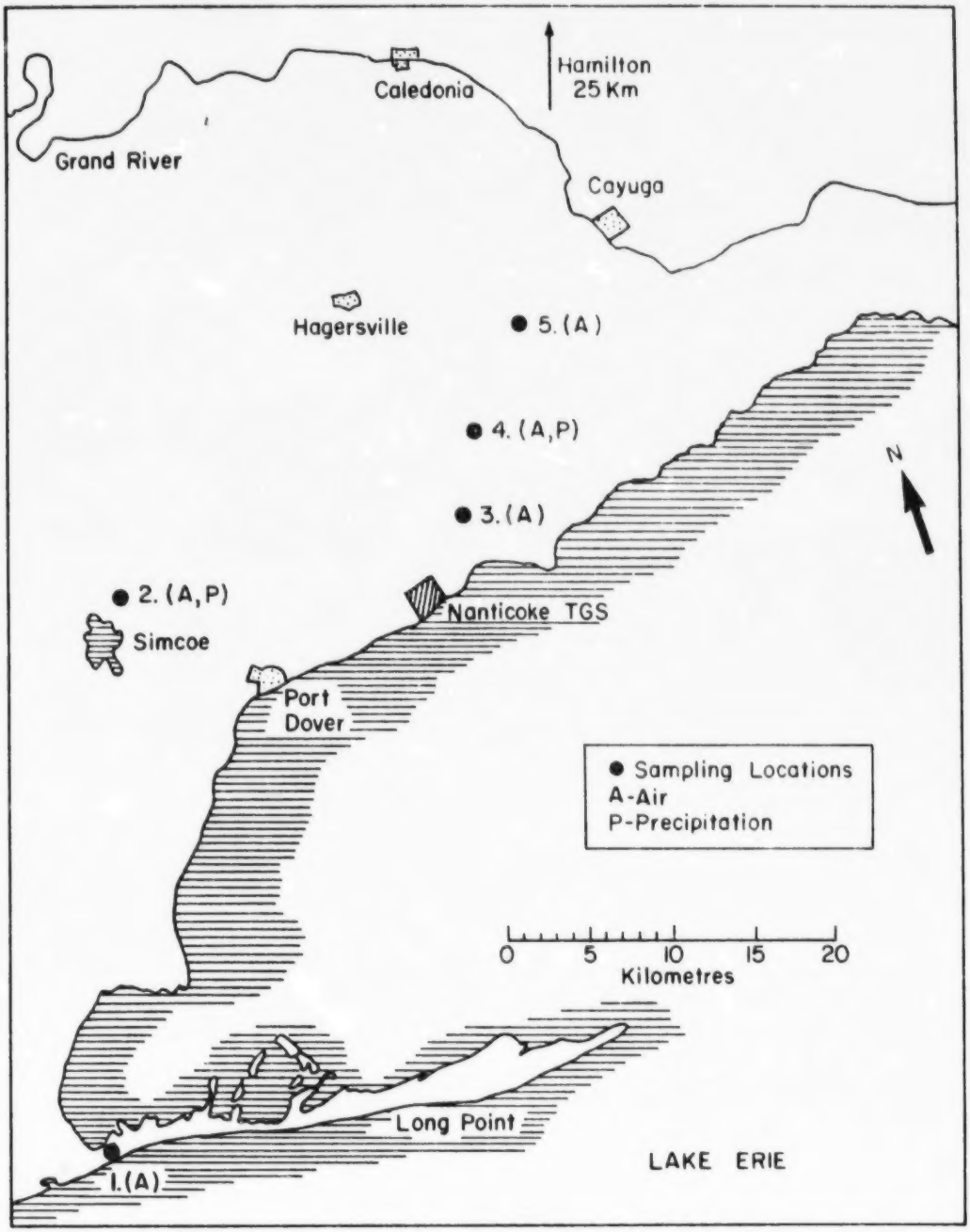



Figure 27. Sampling Stations in the Vicinity of the Nanticoke Thermal Generating Station